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THE UNIVERSITY OF ALBERTA

EFFECT OF BETA-GLUCANS AND PROCESSING METHOD ON THE UTILIZATION OF BARLEY BY CATTLE

BY

DALE FRANCIS ENGSTROM

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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OF MASTER OF SCIENCE

IN

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DEPARTMENT OF ANIMAL SCIENCE

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SPRING 1988

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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **Effect of Beta-glucans and Processing Method on the Utilization of Barley by Cattle** submitted by Dale Francis Engstrom in partial fulfilment of the requirements for the degree of Master of Science in Animal Nutrition.

G. W. Mathison
Supervisor

Frank Ohmann

Date: April 26, 1988

DEDICATION

I dedicate my thesis to my wife, Linda, and to my children Bradley, Adam, Stephen and Gillian. Without their love, support and personal sacrifice I would not have been able to complete this task.

ABSTRACT

A study was undertaken to determine if beta-glucans and other components in barley affected the performance of cattle fed high concentrate diets. In the first experiment six lots of barley (either steam-rolled or dry-rolled) with beta-glucan contents ranging from 3.5 to 4.8% of the dry matter were fed to 120 steers. There were no differences between the barleys in terms of their affect on average daily gain ($P = 0.81$). Feed dry matter:gain ratio (DM:G) was also unaffected ($P = 0.17$) by barley type. No significant differences in performance were detected between cattle fed dry rolled and steam rolled barley. Starch, acid detergent fibre, neutral detergent fibre, volume weight and 24 h in situ dry matter degradability were significantly ($P < 0.05$) correlated with DM:G ($r = -0.83$, 0.95, 0.85, -0.81, -0.91, respectively). Beta-glucan content of the barley was non significatantly related to DM:G ($r = -0.79$; $P = 0.06$), and to daily feed intake ($r = -0.50$; $P = 0.31$). In a second experiment, with four other barley samples, the digestibility of beta-glucans (98.6%) and starch (98.1%) were similiar.

It was concluded that beta-glucans have no significant effect on the nutritive value of grain for feedlot cattle, but that factors such as volume weight, starch content, fiber content, and 24 hour in situ dry matter degradability accounted for a significant proportion of variation in feed conversions when high concentrate diets are fed. Further, steam-rolled barley fed to feedlot cattle does not improve performance or carcass traits in comparison to dry-rolled barley.

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1. INTRODUCTION

Barley is often the cheapest source of energy and the most frequently used grain in the feeding industry of Western Canada. Volume weight, moisture content and dockage have been the main quality criteria considered by commercial feedmills and feedlots (Grimson et al. 1987). Quality of barley for feedlot cattle has been investigated (Thomas et al. 1963; Hinman 1978; Mathison and Milligan 1984; Grimson et al. 1987), but not to the degree that its importance in Western Canada warrants.

Beta-glucans are structural carbohydrates that account for 75% of the endosperm cell wall material of barley grain (Fincher 1975; Ahluwalia and Ellis 1985) and thus surround starch granules. They are also found in the aleurone layer where they constitute approximately 24% of total cell wall material (Bacic and Stone 1981). Beta-glucans are chemically and structurally similar to cellulose except that the glucose residues are beta-1,4 and beta-1,3 linked (Bamforth 1982; Woodward and Fincher 1983).

Beta-glucans have been considered responsible for reduced performance and sticky droppings when barley-based diets were fed to poultry (Gohl et al. 1978). Reduced performance in growing pigs on barley based diets is thought by some (Honeyfield et al. 1983; Taylor et al. 1985) to be related to beta-glucan content. However the ileal digestibility of beta-glucan in swine is high (Graham et al. 1986; Weltzien and Aherne 1987), likely due to the beta-glucanase activity of the lactobaccili population of the small intestine of the pig.

Beta-glucanase activity has been identified in several species of rumen microorganisms (Teather and Wood 1982), but the effect of beta-glucan on the digestion and metabolism of barley in ruminants has not been investigated.

Steam rolling of barley is practiced by many feed manufacturers. Reasons for this include a reduction in the amount of small particles, compared to dry rolling or grinding, the gelatization of starch and improved palatability. However, in two recent feedlot trials conducted in Alberta (Mathison and Milligan 1984; Grimson et al. 1987) steam rolling of barley did not result in improved feed intake, average daily gain (ADG) or feed efficiency.

Differences in volume weight, protein content, starch content, and the various fiber fractions of barley have been investigated by several researchers (Mathison 1984). Hinman (1978) reported that average daily gain (ADG) and feed efficiency of steers was adversely affected by feeding light weight barley. Other results with feedlot cattle (Mathison and Milligan 1984; Grimson et al. 1987) indicate that ADG is not affected by volume weight but that feed efficiency was reduced.

The objective of these experiments was to determine the effect of beta-glucan, starch, fiber content and steam rolling on the intake, digestion, and feed efficiency of barley in finishing diets for cattle.

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2. LITERATURE REVIEW

2.1. Barley Beta-glucans

2.1.1. Structure and Distribution

The carbohydrate portion of barley grain consists of linear glucose polymers of two types (Bamforth 1982). The alpha-glucan polymer (starch) is the major storage carbohydrate in the grain and is identified by the alpha-1,4-linkage of the glucose residues (French 1973; Bamforth 1982; Manners 1985). The beta-glucan polymer found in barley exhibits beta-linkage of the glucose residues and in that sense is similar to cellulose. However, cellulose is a homoglucan exhibiting only beta-1,4-linkage while the beta-glucan of barley contains both beta-1,4 (70%) and beta-1,3 (30%) linkage of the glucose residues (Fleming and Kawakami 1977; Ballance and Manners 1978; Bamforth 1982; Woodward and Fincher 1983). For this reason it is termed a "mixed-linkage" beta-glucan. Various reports in the literature also refer to barley beta-glucan as "barley gums" (Bamforth 1982).

In a 40°C water soluble isolate from two barley varieties, the beta-glucan polymer consisted primarily of blocks of two or three 1,4-linked glucose molecules separated by a single 1,3-linked molecule. However, blocks of four or more 1,4-linked molecules made up over 5% of the beta-glucan polymer. This pattern is very similar to a beta-glucan isolated from oats (Parrish et al. 1960).

According to Woodward and Fincher (1983) glucose accounts for 98% of the monosaccharides found in barley with arabinose, xylose, and

galactose present in small amounts.

Beta-glucan in barley can be divided into two categories: the fraction freely soluble in water or buffer, referred to as the "gum", and the insoluble residue (Forrest and Wainwright 1977; Bamforth 1982). The relative amount of soluble beta-glucan varies with extraction media, temperature, and time. However, 65° C water soluble values are commonly reported and range from 20 to 37% of total beta-glucan in barley flour (Anderson et al. 1978; Martin and Bamforth 1981; McClear and Glennie-Holmes 1985). In isolated endosperm cell walls, a greater proportion of the beta-glucan (up to 75%) are soluble under these conditions (Forrest and Wainwright 1977; Ahluwalia and Ellis 1985). Varietal differences and cell wall isolation techniques may affect the fraction of beta-glucan which is soluble.

Increasing the temperature of aqueous extraction media markedly increases the relative amount of extractable beta-glucan in barley flour and isolated endosperm cell walls (Fleming and Kawakami 1977; Ahluwalia and Ellis 1985). The solubility of beta-glucans decreases with maturity of the grain (Aastrup 1979a; Hesselman et al. 1981).

Barley beta-glucans are not homogeneous with respect to molecular size, fine structure, nor chemical and physical properties, but rather represent a large and diverse group of polysaccharides (Woodward and Fincher 1983). Reviewing the literature, Woodward and Fincher (1983) reported that beta-glucans, isolated from barley flour or endosperm cell walls, varied in molecular weight from 20,000 to 40

million daltons. Their review represented a wide variety of extraction media and temperatures as well as several molecular separation techniques. The larger molecular weight polymers were extracted at higher solution temperatures (Fleming and Kawakami 1977; Woodward and Fincher 1983; Ahluwalia and Ellis 1985). The use of alkali, rather than aqueous media does not appear to extract polymers of significantly different molecular weight (Forrest and Wainwright 1977).

In barley grain, beta-glucans are located primarily in the endosperm cell wall where they account for 70 to 75% of total cell wall material (Fincher 1975; Forrest and Wainwright 1977; Ballance and Manners 1978; Ahluwalia and Ellis 1984,1985). They are also found in the aleurone layer where they constitute approximately 24% of total cell wall material (Bacic and Stone 1981). Pentosans (18 to 20%), proteins (3 to 5%) and mannose make up the remainder of endosperm cell wall composition (Forrest and Wainwright 1977; Bamforth and Martin 1981). Beta-glucans play a structural role in the endosperm cell wall, similar to that of cellulose in other plant tissues (Bamforth 1982). However, because of their mixed-linkages, beta-glucans are much more soluble in water and more easily hydrolyzed than cellulose (Bamforth 1982).

Although protein is a relatively minor component of total cell wall material, it plays a major role in maintaining cell wall integrity. Forrest and Wainwright (1977) reported that 50% of the total beta-glucan could be removed by solubilization in water without

destroying cell wall integrity. However, when endosperm cell walls were incubated with the proteolytic enzyme thermolysin, more than 96% of the beta-glucan was extracted and no cell wall structure could be distinguished under the microscope. Thompson and Laberge (1977), as cited by Weltzien (1986), feel that the beta-glucans are firmly linked to peptide sequences in the cell wall. Forrest and Wainwright (1977) found 5.5 moles of alpha-amino nitrogen per 100 moles of glucose in the hot aqueous extract from endosperm cell walls, an indication that peptide bonds may also be present in the soluble beta-glucans.

In developing grains, beta-glucans can be detected at low levels as early as 12 days after anthesis, and reach maximal concentrations around 30 days after anthesis (Prentice et al. 1981). Physiologically the structural role of beta-glucans is important in the developing barley endosperm, but less so in the mature kernel (Thompson and Laberge 1981). Endosperm cell walls completely enclose the cell making starch granules and storage proteins largely inaccessible to the endogenous degrading enzymes (Morgan and Gothard 1977; Allison et al. 1978; Bamforth 1982). Thus degradation of endosperm cell walls, specifically beta-glucan complexes, must occur before the food reserves can be enzymatically hydrolysed.

2.1.2. Beta-glucan Content of Barley and Other Grains

Mixed-linkage beta-glucans are found in a variety of plant tissues but endosperm cell walls of some species are particularly

rich in this type of beta-glucan (Bamforth 1982). The total beta-glucan content of barley grain has been reported to be as low as 2.9% (Bourne et al. 1982) and as high as 13.5% (Newman 1986). Several authors have reported values within this range (Anderson et al. 1978; Prentice et al. 1981; McClear and Glennie-Holmes 1985). These extremes are due in part to method of extraction and analysis, but also to genetic and environmental effects. Anderson et al. (1978) reported that four Canadian barley varieties grown at two prairie locations had beta-glucan levels of 3.77 to 5.62%. Eleven other varieties from around the world had beta-glucan levels of 3.64 to 6.44% which indicates that Canadian barley is similar to world barley.

Varietal differences account for much of the variation in the beta-glucan content of barley. Ullrich et al. (1986) reported that four waxy barley lines had a mean beta-glucan content of 6.4% compared to 4.8% in the normal isogenic pairs. Hulless mutants of waxy barley may contain up to 13.5% total beta-glucan (Newman 1986.) Bourne and Wheeler (1984) reported that the ranking of four barley varieties for beta-glucan content was identical over seven locations and three crop years. Molino-Cano and Conde (1982) reported that genetic factors accounted for 89% of the variation in beta-glucan content.

Environment also has a pronounced effect on beta-glucan content. Bourne and Wheeler (1984) found variations of up to 25% between locations for a single variety. Molino-Cano and Conde (1982) reported

that sowing date accounted for 12.5% of the variation in beta-glucan content and that location accounted for 10%. European research indicated that drought stress at all stages of crop development increased beta-glucan content (Coles 1979; Morgan and Riggs 1981). Watering from a sprinkler versus root irrigation was found to decrease beta-glucan content (Aastrup 1979b; Coles 1979). It is suggested that beta-glucans, because of their hygroscopicity, may perform an osmoregulatory function as well as a structural role in plants (Bamforth 1982). However, recent work in the northwestern United States reported that beta-glucan content was higher in five barley cultivars grown under irrigation compared to dryland conditions (Honeyfield et al. 1987).

Since beta-glucans comprise 70 to 75% of the endosperm cell wall it is reasonable to assume that varieties with thicker cell walls would have higher levels of beta-glucans in the total grain. This is confirmed by Aastrup and Munck (1985) who studied cell wall thickness of Minerva barley and its low beta-glucan mutant.

Beta-glucan levels reported for oat grain range from 2.5 to 6.6% of total dry weight. Rye grain levels have been reported at 1.4 to 2.3%, and wheat, triticale, corn, rice and sorghum are found to be low (< 1%) in beta-glucans (Anderson et al. 1978; Wood et al. 1978; Prentice et al. 1981; McClear and Glennie-Holmes 1985).

2.1.3. Beta-glucanases

Barley beta-glucans are diverse in nature particularly with

respect to molecular weight (Woodward and Fincher 1983) and to the ratio of beta-1,3 to beta-1,4 linkages (Flemming and Kawakami 1977). Also, the bonding of beta-glucans to other compounds such as proteins plays a significant role in cell wall integrity (Forrest and Wainwright 1977). For these reasons a spectrum of enzymes is required to completely degrade beta-glucans of the endosperm cell wall to glucose.

The solubilase enzyme is endogenous to mature barley grain and increases rapidly during seed germination (Bamforth et al. 1979). During germination solubilase is noted in the embryo by day two, in the middle section by day three, and in the distal portion by day four (Morgan et al. 1983). It is extremely heat stable and upon purification has been identified properly as a carboxypeptidase rather than a true beta-glucanase (Bamforth et al. 1979). Martin and Bamforth (1980) found a direct correlation between the amount of solubilase and the extent of beta-glucan release during autolysis. It likely hydrolyses the peptide bonds involved in binding beta-glucan to the cell wall matrix (Forrest and Wainwright 1977; Bamforth et al. 1979). Baxter (1978) found solubilase to exhibit esterase activity and it may be involved in hydrolysis of an ester linkage between beta-glucan and glutamate or aspartate (Bamforth et al. 1979; Bamforth and Martin 1981). Thus, solubilase has a role in the extraction of beta-glucan (Martin and Bamforth 1980).

Endogenous endo-beta-glucanases of three types have been characterized: (1) endo-beta-1,3-glucanase (2) endo-beta-1,4-

glucanase and (3) endo-beta-1,3-1,4-glucanase (Bamforth 1982). The latter is also referred to as endo-barley-beta-glucanase. Endo-beta-1,3-glucanase activity in barley has been reported by several authors (Manners and Marshall 1969; Ballance et al. 1976; Manners and Wilson 1976; Ballance and Manners 1978). Ballance et al. (1976) found that most of the activity was located in the embryo and scutellum of unsteeped barley kernels, and that during germination this activity increased markedly in the aleurone and endosperm. Manners and Marshall (1969) suggested that the substrate for this enzyme may be callose (a beta-1,3-glucan) while Bathgate and Palmer (1974) suggest that this enzyme is responsible for degrading beta-glucan in the early stages of germination. Ballance and Manners (1978) isolated an endo-beta-1,3-glucanase from malted barley that caused extensive solubilization of endosperm cell wall polysaccharides.

Endo-beta-1,4-glucanase is not detected in unsteeped barley (Ballance et al. 1976). After steeping it is detected primarily in the husk where it is thought to degrade cellulose (Ballance et al. 1976; Bamforth 1982). Manners and Marshall (1969) indicated that this enzyme is the largest in the barley beta-glucanase system having a molecular weight of 20,000 daltons.

Endo-barley-beta-glucanse specifically hydrolyzes a beta-1,4 linkage with a beta-1,3 linkage on the non-reducing side and a beta-1,4 linkage on the reducing side (Parrish et al. 1960; Manners and Wilson 1976; Woodward and Fincher 1982). Woodward and Fincher

(1982) purified two monomeric forms from germinating barley that hydrolyzed barley beta-glucan at significantly different rates and exhibited different thermostability. One monomer lost more than 50% of original activity after heating at 40°C, while the other maintained 86% of original activity. Neither were stable at 60°C. However, Gohl et al. (1978) found more than 80% of beta-glucanase activity was retained in barley that was subjected to 130°C for 20 minutes. Ballance et al. (1976) also found two similar enzymes with endo-barley-beta- glucanase activity. Activity was negligible in all but hull tissue in unsteeped barley, but was detected in the hull, embryo, scutellum, alleurone and endosperm after three days germination. Activity was markedly higher in the endosperm.

A number of fungal species have been reported to exhibit beta-glucanase activity of some type (Ballance and Manners 1978; Bamforth 1983; Hesselman and Aman 1985). Several bacterial species have also shown beta-glucanase activity (Huber and Nevins 1977; Anderson et al. 1978; Graham et al. 1986). Numerous rumen microbial species possess the enzymes necessary for cellulose (beta-1,4 linkage) degradation in plant cell wall material (Hungate 1975; Akin 1986). Specific endo-beta-1,4-glucanase activity has been reported (Pettipher et al. 1979; Groleau and Forsberg 1981). Endo-barley-beta glucanase activity, required to hydrolyze mixed-linkages, has been previously reported in the cultures of rumen fluid (Teather and Wood 1982).

2.1.4. Effects of Beta-glucans on Extract Viscosity

Aastrup (1979a) extracted beta-glucans, and other compounds, from 18 varieties of barley with an acid buffer (pH = 1.5). Viscosity of acid extracts was determined and found to correlate well with percent soluble beta-glucan content (R^2 = 0.99), but less so with total beta-glucan (R^2 = 0.78). Smith et al. (1980a) reported similar correlations. In the acid extracts of three varieties, beta-glucan content represented 14, 38, and 41% of the total carbohydrate, but was responsible for 70.0, 98.5 and 99.5% respectively of the viscosity (Aastrup 1979a). Smith et al. (1980a,b) confirmed that beta-glucan made the major contribution to acid extract viscosity. Hesselman et al. (1981) found that acid extracts (pH = 1.5) were approximately twice as viscous as the aqueous extracts of one barley variety. For barley varieties exhibiting high extract viscosity, Aastrup (1979a) found that maleate buffer extracts (pH = 6.5) had viscosities similar to those obtained at pH 1.5. However, the variety exhibiting low extract viscosity at pH of 1.5 showed a two fold reduction in viscosity compared with the extract obtained at a pH of 6.5.

beta-glucans are also responsible for the viscosity observed in aqueous extracts of barley (Preece and MacKenzie 1952; Burnett 1966). Bendelow (1975), using a complex enzymatic extraction technique, also concluded that viscosity due to components other than beta-glucans was insignificant. Viscosity of aqueous extracts is related to source of barley and processing (Burnet 1966). Heat and/or steam treatment generally increased extract viscosity, likely by inactivating

endogenous enzymes (Burnett 1966; Gohl et al. 1978).

Wood et al. (1978) reported that alkali extracts (pH = 10) of two oat varieties were higher in both beta-glucan content and viscosity than two barley varieties.

2.1.5. Endosperm Modification

During germination endosperm cell walls must first be disrupted to allow starch and protein reserves to become accessible to endogenous or exogenous enzymes (Bamforth 1982; Enari and Sopanen 1986). The beta-glucan content of barley is highly correlated (R^2 = 0.95) with the modification of endosperm tissue during germination, as is the beta-glucanase activity (Aastrup and Erdal 1980). Martin and Bamforth (1980) agree that beta-glucan content of barley influences modification rate but indicate that solubilase activity plays a role as well.

2.1.6. Nutritional Effects

If left undegraded after ingestion beta-glucans could be expected to impart viscosity to digestive tract contents. The viscosity of intestinal contents of three-week-old chicks was increased three fold by the addition of exogeneous beta-glucans to the basal diet (White et al. 1981). White et al. (1983) isolated a beta-glucan polymer with a molecular weight of 47,000 from the intestinal contents of chicks fed a barley based diet.

Beta-glucans are generally believed to be the compound in barley

that reduces chick growth rate and feed efficiency and increases the moisture content and stickiness of droppings (Burnett 1966; Gohl et al. 1978). The effect is more pronounced in young chickens than in mature layers (Peterson and Sautner 1968; Gohl et al. 1978). Gasaway (1974) claims that broiler chickens lack beta-glucanases in their digestive tract. The digestibility of dry matter and some other nutrients is thought to be adversely affected by beta-glucans by some workers (Herstad and McNab 1975; Hesselman and Aman 1985) but not by others (Gohl and Thompke 1976).

Evidence that beta-glucans are responsible for the lower nutrient value of barley for chickens is supported by the improvements seen in performance when beta-glucanases are supplemented to the diets of young chickens. Improvements in growth rate and feed efficiency, as well as increased dry matter and reduced stickiness of droppings have observed when a beta-blucanase is added to the diet (Gohl et al. 1978; White et al. 1980; Hesselman et al. 1981,1982; Cambell et al. 1987). The dietary inclusion of even crude preparations of bacterial and plant enzymes have lead to improved performance of chickens fed barley based diets (Daghir and Rottensten 1966; Herstad and McNab 1975).

The reason for the improved performance with enzyme supplementation cannot be attributed to additional glucose becoming available from hydrolyzed beta-glucan. If all the beta-glucan were hydrolyzed to glucose only 3% more glucose would be available, whereas improvement in growth is commonly observed to be 15 to 20%

(White et al. 1983). The viscosity that beta-glucans impart to intestinal contents is thought to adversely effect the mixing of food with enzymes, and to interfere with normal nutrient transport properties at the mucosal surface (White et al. 1981,1983).

Both the addition of water and anaerobic storage appear to activate endogenous beta-glucanases in barley, and have improved the nutrient value of barley for chickens (Gohl et al. 1978; Hesselman et al. 1981). Autoclaving barley, presumed to inactivate endogenous enzymes, reduced chick performance (Herstad and McNab 1975: Gohl et al. 1978). However, these effects are not seen with all barley diets. Gohl et al. (1978) reported the expected improvements in performance with both water treatment and beta-glucanase supplements to a barley that yielded a high acid extract viscosity. When the same treatments were applied to a barley of medium extract viscosity, no significant differences were observed. This provides additional evidence that it is the viscosity of barley that reduces its nutrient value.

Beta-glucans appear to cause similar but less severe problems in other monogastrics. Bhatty et al. (1974) reported a weak correlation ($r = -0.16$) between the digestion coefficient of barley and its beta-glucan content when fed to mice. Gohl and Gohl (1977) reported that beta-glucans and similar gums delayed the passage of digesta in rats. Several workers have reported that beta-glucans are responsible for reduced performance in growing pigs, and for lowered digestibility of certain dietary components (Froseth et al. 1981; Honeyfield et al. 1983; Taylor et al. 1985). Newman et al. (1980)

found that bacterial diastase, a source of beta-glucanase, produced a small improvement in daily gain in diets based on a covered barley, but no improvement in a hulless barley. However, others have reported no significant difference in the performance of pigs fed barley cultivars of different beta-glucan content (Davies and Radcliffe 1984) but very young pigs may be more susceptible to the effects of beta-glucans (Thomke et al. 1980).

Beta-glucans appear to be readily digestible in the small intestine of swine. Digestibility coefficients of 70 to 80% at the terminal ileum have been reported (Graham et al. 1986; Weltzien and Aherne 1987). Graham et al. (1986) isolated lactobacilli from duodenal and ileal digesta that were capable of degrading mixed-linkage beta-glucans. They concluded that bacterial and endogenous enzymes degraded beta-glucans to the point where beta-glucanase supplementation would be of limited value.

To the writers' knowledge, the effect of beta-glucans on the digestion and metabolism of ~~ruminants~~ has not been previously reported.

2.1.6. Methods of Beta-glucan Analysis

A variety of methods for beta-glucan determination have been developed, mostly by researchers in the brewing industry. Differences in the extraction techniques result in different beta-glucans being available for measurement (Woodward and Fincher 1983), and are responsible for a large part of the variation reported in beta-glucan

content of barley (Anderson et al. 1978).

Most quantitative procedures start with boiling the sample in 80 to 85% ethanol for about five minutes to inactivate endogenous enzymes and to remove soluble sugars (Fleming and Kawakami 1977; Anderson et al. 1978; Bamforth 1983; Henry 1984). A highly efficient procedure (Ahluwalia and Ellis 1984) employs weak perchloric acid for this purpose.

2.1.6.1. Extraction

Extraction techniques vary depending on the beta-glucan fraction that is to be determined. Aqueous extraction media at 40 to 60°C are often used to measure water soluble beta-glucan, a fraction of importance to the brewing industry (Martin and Bamforth 1981; Bamforth 1982; Woodward and Fincher 1983). Alkali extraction has been used on endosperm cell wall preparations (Forrest and Wainwright 1977) and bicarbonate buffer has been used on barley flour (Prentice et al. 1980). Acid extraction media have been used, especially when viscometric techniques are employed to estimate beta-glucan content (Greenberg and Whitmore 1974; Morgan and Gothard 1977). Bendelow (1975) used a mixture of alpha-amylase and papain to extract beta-glucans for viscosity measurements. The weak perchloric acid media (50 mM) used by Ahluwalia and Ellis (1984) extracts all beta-glucan and starch polymers in only three minutes at 96°C. For some time hydrazinolysis was the best method available for complete extraction of beta-glucans and was used when total beta-glucan was to

be determined (Anderson et al. 1978; Martin and Bamforth 1981; Bamforth 1983). However, the removal of hydrazine by dialysis prior to the measurement of beta-glucans also removes low molecular weight beta-linked oligosaccharides, giving an underestimate of total beta-glucans. Several beta-glucanases have been recently reported to be effective in degrading beta-glucans in barley flour without prior chemical extraction (Anderson et al. 1978; Henry 1984; Aman and Hesselman 1985).

2.1.6.2. Indirect Measurement

Once extracted, beta-glucans can be measured in several ways. Soluble beta-glucan content correlates well with extract viscosity, (R^2 = 0.99), (Aastrup 1979a), and this feature can be used to rapidly screen large numbers of barley samples (Greenberg and Whitmore 1974; Bendelow 1975; Morgan and Gothard 1977). Allison et al. (1978) found that infrared reflectance spectroscopy predictions correlated fairly well (r = 0.87) with soluble beta-glucans. However, values used for percent soluble beta-glucans were actually predicted from extract viscosity and were not made by direct measurement. Jensen and Aastrup (1981) reported a fluromertic procedure that utilizes the binding of beta-glucan to the optical brightener Calcoflour. The method is rapid and reproducible, but requires calibration with an independent method (Aman and Hesselman 1985).

Acid hydrolysis of the extract yields glucose, mainly from beta-glucans and starch. By comparing this amount with the amount of

glucose liberated from starch by amyloglucosidase, beta-glucan content can be calculated by difference (Fleming et al. 1974; Fleming and Kawakami 1977). This method is subject to error if large quantities of starch are present (Bamforth 1982), if the amyloglucosidase or acid hydrolysis reactions don't go to completion (Martin and Bamforth 1981), or if there is beta-glucanase activity in the amyloglucosidase preparation (Bendelow 1975).

2.1.6.3. Enzymatic Quantification

beta-glucanases which specifically degrade beta-glucans are used in the most reliable quantitative procedures (Bamforth 1982). Crude enzyme preparations (commercial cellulases and amylases) contain alpha-amlyase as well as beta-glucanase. Pure beta-glucanase activity can be obtained by several methods. Heat treatment (70 to 90°C), followed by dialysis, is effective because beta-glucanases are generally more heat stable than amylases (Martin and Bamforth 1981; Bamforth 1983). Ion exchange chromatography, using DEAE-cellulose, has been effective in a column (McClear and Glennie-Holmes 1985) and a filter apparatus (Prentice et al. 1980). Further purification of elutant has been accomplished with gel chromatography (Weltzien and Aherne 1987) and by precipitation of remaining amylase activity with starch and ethanol (Henry 1984).

After purification, beta-glucanase activity from several sources has been effective in assays. beta-1,3-1,4-glucanase activity was purified by Anderson et al. (1978) from Bacillis subtilis. This

enzyme specifically depolymerized beta-1,4-linkages in mixed-linkage polymers. The oligosaccharides released were then acid hydrolyzed to glucose. beta-glucanase purified from Trichoderma reesi (also called T. viride) completely hydrolyzed beta-glucans to glucose (Prentice et al. 1980; Martin and Bamforth 1981), as did the purified enzyme from Penicillium funiculosum (Bamforth 1983; Ahluwalia and Ellis 1984). The beta-glucanase used by Anderson et al. (1978) and Henry (1984) were capable of degrading beta-glucans in finely ground barley and thus prior extraction procedures were not required.

The measurement of liberated glucose is commonly done enzymatically using hexokinase/glucose-6-phosphate dehydrogenase (Martin and Bamforth 1981; Ahluwalia and Ellis 1984). Other methods have also been reported using p-hydroxybenzoic acid hydrazide (PAHBAH) (Henry 1984), glucose-oxidase (Bamforth et al. 1979) and chromatography (Prentice et al. 1980).

2.2. Starch Digestion in Ruminants

2.2.1. Form and Structure of Cereal Grain Starch

Starch occurs in most green plants where its role is as a store of energy for future use (Van Soest 1982). The starch content of cereal grains represents 60 to 80% of total dry weight and is a major source of highly digestible energy for livestock throughout the world (Rooney and Pflugfelder 1986). Starch is an alpha-linked polymer composed of two major types of molecules; amylose and amylopectin (French 1973; Manners 1985; Rooney and Pflugfelder 1986). In cereal

grain starch occurs primarily within the endosperm cells of the kernel (Briggs 1978).

Most cereal starches contain 20 to 30% amylose and 70 to 80% amylopectin, though "waxy" varieties of corn, sorghum and barley contain almost all (99%) amylopectin and "high amylose" varieties contain up to 80% amylose (Manners 1985; Rooney and Pflugfelder 1986).

Amylose consists of almost entirely of long linear chains of alpha-1,4-linked D-glucose units (French 1973; Manners 1985) though very limited branching may also occur (Hizurkuri 1981; Whistler and Daniel 1984; Rooney and Pflugfelder 1986). Average chain length is approximately 10^3 and the chain is in the form of a helix (French 1973; Manners 1985; Rooney and Pflugfelder 1986).

Amylopectin is a much larger polymer than amylose and has linear alpha-1,4-linked chains which have alpha-1,6 branch points every 20 to 25 glucose units (French 1973; Manners 1985; Rooney and Pflugfelder 1986). The total number of glucose units in amylopectin range from 1,000 to 500,000 (French 1973).

2.2.2. Starch Granules

Rooney and Pflugfelder (1986) state "starch exists in highly organized granules in which amylopectin and amylose molecules are held together by hydrogen bonding". Starch granules contain highly organized crystalline areas as well as non-organized amorphous (gel-like) areas (French 1973; Rooney and Pflugfelder 1986). Granules

vary in size, from sub-micron to greater than 200 microns, depending on the type of plant tissue, and are synthesized in the amyloplast during seed development. Cereal and root starches can be differentiated by their x-ray pattern and exhibit birefringence (French 1973; Rooney and Pflugfelder 1986). Granules are minimally hydrated which permits a large amount of carbohydrate to be stored in a small volume (French 1984). The granule may contain a small amount of non-carbohydrate components such as lipids, proteins, phosphate and ash (French 1984).

The amorphous region of the granule (gel phase) is rich in amylose and freely accepts water (French 1984; Rooney and Pflugfelder 1986). Water uptake in the gel phase causes swelling and stress through the entire granule (French 1984). Dehydration increases inter- and intra-hydrogen bonding and also causes strain on the entire structure to the extent that fractures become visible in the granule (French 1984). Enzyme attack on the granule begins in the amorphous region (French 1984).

The crystalline area of the starch granule is thought to be primarily composed of amylopectin (Rooney and Pflugfelder 1986), though granules of "waxy" starches do exhibit amorphous regions (Manners 1985). The crystalline area is resistant to water entry and to enzyme attack or acid hydrolysis (Manners 1985; Rooney and Pflugfelder 1986). It is also responsible for the birefringence of the granule (Rooney and Pflugfelder 1986). Both French (1984) and Manners (1985) consider the starch granule to consist of radial

chains of amylopectin separated by amylose molecules, though the exact role of amylose in the structure is not known (Rooney and Pflugfelder 1986). Growth rings in the granule are visible with scanning electron microscopy after the amorphous layers have been attacked by enzymes (French 1984).

2.2.3. Gelatinization

Gelatinization of the granule generally refers to the swelling and loss of crystallinity that occurs in the presence of water and heat. The swelling is reversible if the temperature of the granule remains below about 55°C, but once the "gelatinization temperature" is reached (60 to 80°C) the swelling and subsequent loss of crystallinity is irreversible (French 1973,1984; Rooney and Pflugfelder 1986). Gelatinization is highly dependant upon the presence of free water in the granule and considerable more mechanical, thermal, or chemical energy is required to cause gelatinization in the absence of free water (Maurice et al. 1985 as cited by Rooney and Pflugfelder 1986). Gelatinization, with heat and water, starts with the swelling of the amorphous region which puts strain on the crystalline areas. Amylose is leached from the granule in the early stages of gelatization. Continued swelling and heating results in the melting and hydration of the crystalline region (French 1984: Rooney and Pflugfelder 1986). The resulting loss of crystallinity yields a granule that is much more susceptible to enzymatic attack (McRae and Armstrong 1968; Rooney and Pflugfelder

1986).

The degree of gelatinization in a starch can be measured by changes in viscosity, loss of birefringence, differential scanning calorimetry, changes in swelling and solubility, and susceptibility to enzymes (Zobel 1984). Loss of birefringence and enzyme susceptibility are the methods used when evaluating gelatinization of feed grains (Rooney and Pflugfelder 1986).

2.2.4. Retrogradation

Retrogradation refers to the return of swollen, gelatinized or dissolved starch to an aggregated or insoluble form (French 1973). It results in a three-dimensional network of mainly amylose (Young 1984). The extent of retrogradation is dependant upon the fine structure of amylose and amylopectin, moisture content, temperature, complexing agents and starch concentration (Rooney and Pflugfelder 1986). Thus, retrogradation can be considered a realignment of the molecules and the oposite of gelatinization. When processed grain is used for livestock feed retrogradation may decrease digestibility (Van Soest 1982; Rooney and Pflugfelder 1986).

2.2.5 Dextrinization

Dextrinization is the formation of amylose and amylopectin fragments through the heating of dry starch in the presence of moisture, acids or salts. Some enzyme resistant glycosidic bonds may be formed and thus the process is undesirable in terms of maximizing

starch digestibility (Rooney and Pflugfelder 1986).

2.2.6. Digestion of Cereal Grain Starch

Among native polysaccharides, starch is one of the most digestible for the ruminant animal which has both microbial and endogenous amylases available to hydrolyze starch. In monogastrics the digestibility of starch is generally affected by its composition and physical form, protein interactions, integrity of starch containing cells, anti-nutritional factors and physical form of the grain (Thorne et al. 1983; Dreher et al. 1984).

2.2.6.1. Hydrolases

According to Rooney and Pflugfelder (1986), several starch hydrolases exist. Alpha-amylases exhibit endo-amylase activity, hydrolyzing alpha-1,4 glucosidic bonds at random and producing maltose and branched and linear dextrins. Beta-amylases exhibit exo-amylase activity attacking alternate alpha-1,4-linkages and producing maltose as the only end product. Glucoamylases (amyloglucosidases) hydrolyze both alpha-1,4 and alpha-1,6-linkages from the reducing end of a residue producing only glucose. The debranching enzymes, pullanases and isoamylases, exhibit endo-alpha-1,6 activity producing linear fragments (dextrins) of glucose. The latter two are important in that they produce numerous short chain linear dextrins that can be attacked by beta-amylases.

Dreher et al. (1984) report that, in the monogastric, cereal starches are generally more easily digested than root or tuber starches. Legume starches are intermediate in terms of their digestibility. This is supported by other work with pancreatic and bacterial enzymes (Banks and Greenwood 1975 as cited by Rooney and Pflugfelder 1986; Moran 1982). However, major differences exist even within the cereal group (Waldo 1973; Galyean et al. 1981).

Rooney and Pflugfelder (1986) suggest that the proportion of amylose in a starch is one factor affecting its digestibility in monogastrics because high amylose cereal cultivars are less digestible than those high in amylopectin. This applies to corn and sorghum (Rooney and Pflugfelder 1986) but the results are not consistent with barley. Krall (1973), as cited by Newman et al. (1978), reported that calves fed low energy diets gained weight mor quickly when fed a high amylose barley (var. Glacier) compared with those fed a normal barley. However, with diets high in digestible energy calves fed the high amylose barley were less efficient in feed conversion. For growing rats, high amylose barley (var. Glacier) has been reported to be superior to low amylose barley (Rubin et al. 1974 as cited by Newman et al. 1978). However, Calvert et al. (1976) reported the purified starch of the high amylose cultivar to be inferior as an energy source for rats. Newman et al. (1978) suggest that the higher lysine content of the high amylose cultivar may be the dominant factor in the improved performance.

In some cereal species starch granules are imbedded in a protein

matrix. Parts of the endosperm of corn and sorghum exhibit this characteristic and reduced digestibility of this fraction is observed (Rooney and Pflugfelder 1986). Anti-nutritional factors such as amylose inhibitors, phytates, lyso-lecithins, and tannins are known to reduce starch digestibility (Dreher et al. 1984).

2.2.6.2 Site of Digestion

In ruminants, starch digestion occurs primarily by microbial fermentation in the rumen and secondarily by the action of endogenous enzymes in the small intestine (Waldo 1973; Owens et al. 1986; Theurer et al. 1986). Any starch passing these major sites of digestion is subjected to further microbial fermentation in the large intestine (Owens et al. 1986).

Several species of amylolytic rumen bacteria and protozoa have been isolated (Hobson 1979; Russell and Hespell 1981; Baldwin and Allison 1983). The end products of starch hydrolysis are primarily organic acids, methane, and carbon dioxide, and vary with the microbial species. Species of microorganisms also exist that rely on the products of initial starch hydrolysis (dextrins and maltose), or the acidic fermentation products such as lactate or formate (Russell and Hespell 1981; Baldwin and Allison 1983). Protozoa, in addition to hydrolyzing starch, are thought to engulf starch granules thereby preventing the granules from being rapidly fermented to lactate, an undesirable intermediary if present in large quantities (Russell and Hespell 1981). The volatile fatty acids produced by starch

fermentation are absorbed through the rumen wall and make a major contribution to energy metabolism in the ruminant (Baldwin and Allison 1983; Van Soest 1982). The molar proportion of the major volatile fatty acids shifts in favor of propionate when starch rather than cellulose or hemicellulose is fermented in the rumen (Church 1976; Orskov 1986).

Starch is highly digestible in the total ruminant tract. Waldo (1973) reported a mean total tract digestibility of 99% over 51 observations in feeding trials that included corn, sorghum, and barley fed to sheep and cattle. Owens et al. (1986), in a more recent review, found that in 40 cattle trials with corn and sorghum total tract digestibility of starch averaged 92.1%. Spicer et al. (1986) reported total tract starch digestion of 99.2, 99.1, and 97.2% when barley, corn and sorghum where fed to steers.

The proportion of total starch digested in the rumen is high. Waldo (1973) reported rumen digestion coefficients of 94, 78, and 76% for barley, corn and sorghum, respectively. The standard deviations reported in this review were 2.4, 2.5, and 22.4%, respectively. The high coefficient and low standard deviation for barley starch suggests that little response to processing can be expected and that barley starch is relatively uniform in structure. More recently Spicer et al. (1986) reported rumen digestion coefficients in steers of 87.7, 83.7, and 75.2% for barley, corn and sorghum.

Starch presented to the abomasum, after being subjected to ruminal attack, cannot be considered identical to the dietary starch

entering the rumen. It includes the less soluble forms of starch plus microbial starch (Owens et al. 1986). Nonetheless, post-ruminal digestion efficiency of starch is also high. Spicer et al. (1986) reports starch disappearance of 92.9, 93.8, and 87.3% for barley, corn and sorghum respectively when expressed as percentage of the starch entering the abomasum. Owens et al. (1986) found lower values for corn (77.2%) and sorghum (66.5%) when summarizing 28 trials. Large particle size may be the major limitation to starch digestion in the small intestine of ruminants (Owens et al. 1986).

The efficiency of utilization of ingested starch will be influenced by the site of digestion. If fermented in the rumen, losses in energy due to methane (up to 9%) and heat of fermentation (5 to 9%) may occur (Russell 1981). Also, the efficiency of utilization of absorbed glucose is greater than the absorbed products of rumen fermentation (Black 1971). Armstrong et al. (1960) reported that glucose infused into the rumen was used only 69 to 76% as efficiently for gain as glucose infused into the abomasum of sheep. Based on the data of Hale and Prouty (1980), Owens et al. (1986) concluded that corn and sorghum starch fermented in the rumen is used only 70% as efficiently, for gain by steers, as starch digested in the small intestine. Thus, starch digested in the small intestine provides more net energy than starch digested in the rumen.

2.2.6.3 Effect of Processing Grains on Starch Digestion

In this section processing refers to physical destruction of

grain kernel integrity with, or without, heat or chemical treatment. Grinding, cracking and rolling of air dry grains reduces particle size but does little in terms of starch granule gelatinization (McNeill et al. 1975; Galyean et al. 1981). Rolling after steaming produces a steam rolled or flaked product that does exhibit some degree of gelatinization (Hale 1980; Galyean et al. 1981). All of these methods are currently used in the livestock feeding industry of Western Canada and their effect on starch utilization will be discussed in brief. Extreme methods of processing such as micronizing, popping, exploding, and roasting will not be discussed. Processing of grains for sheep and goats is of less importance than it is for cattle (Barnes and Orskov 1982). Generally the effect of processing corn and sorghum on the nutritive value of the grain is much more pronounced than is the effect of processing barley (Waldo 1973).

2.2.6.4. Dry Methods

The dry processing methods (grinding, cracking, rolling) reduce particle size and increase the surface area exposed to enzymatic activity (Matsushima 1980). These methods also rupture the seed coat or husk, a tissue that by design is somewhat resistant to microbial penetration (Galyean 1981; Orskov 1986), also occurs. To a certain extent endosperm cell walls will also be destroyed (Hesselman and Aman 1985). These methods invariably increase the degradability of starch in the rumen, and therefore increase total tract digestibility

of starch (Galyean et al. 1981; Orskov 1986; Theurer 1986). Post-ruminal digestion of starch can also be improved by dry processing methods (Owens et al. 1986). Small particle size maximizes post-ruminal digestion (Owens et al. 1986). However, very small particle size can be detrimental overall in that fermentation of starch in the rumen occurs too rapidly. This causes a sharp reduction in rumen pH and has been associated with bloat, acidosis, rumenitis and liver abscess (Barnes and Orskov 1982; Orskov 1986). Hironaka et al. (1979) found that rumenitis and the presence of abnormal papillae decreased as particle size of an all-concentrate diet increased. Rate of gain, feed intake and protein digestibility were maximized for cattle fed the medium particle size (868 μm) diet. Feed efficiency and digestible energy content were not affected by particle size.

2.2.6.5. Steam Methods

Steam rolling or flaking of cereal grains disrupts the seed coat and gelatinizes the starch (Hale 1980). The flaking process also disrupts the protein matrix surrounding starch granules, a factor that is important in corn and sorghum (McNeill et al 1975). Gelatinization is accomplished by the steam treatment and the pressure of the subsequent rolling (Van Soest 1982). The rolling or flaking portion of the process is critical to the improvement in enzymatic starch digestibility and is independent of particle size (Osman 1970; Frederick et al 1973; Galyean et al. 1981). With corn, steaming without subsequent flaking does not improve starch

digestibility in the total tract (Ramirez et al. 1985).

2.2.6.6. Effect of grain processing on performance

Performance trials don't always support the conclusions reached with in vitro or digestibility trials. This is particularly true with respect to the effects of processing barley. For sheep and goats the feeding of whole barley is recommended because very little whole grain leaves the rumen (Barnes and Orskov 1982). Several trials have indicated that for lambs whole grain feeding is preferred to even minimal processing (Tait and Bryant 1973; Orskov and Fraser 1972; Orskov and Mehrez 1975).

For cattle minimal processing of dry bafley is generally recommended (Hale 1980; Barnes and Orskov 1982; Orskov 1986). This includes coarse grinding or rolling. Steam rolling or flaking is a more expensive method of processing and has not always lead to improved performance. Early work (Hale 1966; Christensen et al. 1968; Parrot 1969) indicated that steam rolling could improve the digestibility of barley, but other reports show no advantage in the performance of cattle fed steam-rolled or flaked compared to cattle fed dry-rolled barley (Garret 1965; Mathison and Milligan 1984; Grimson et al 1987). Mathison and Milligan (1984) observed an increase in bloat in in cattle fed steam- versus dry-rolled barley.

The variability in results observed with steam-rolled or flaked barley in cattle rations could be due to the application of too little heat, too much heat, or retrogradation (Van Soest 1982). Also,

total gelatinization of the starch in corn which was fed to steers markedly reduced their performance (DeBie and Woods 1964).

2.3 Factors in Grain Bloat

Bloat, or ruminal tympany, is the abnormal distension of the ruminoreticulum caused by retention of the gases of fermentation (Blood et al. 1979; Howarth et al. 1986). With frothy bloat the gases remain dispersed throughout the rumen contents in a persistent foam and are not free for eructation (Reid et al. 1975). In free gas bloat the gases are separate from the rumen contents but accumulate in pockets within the rumen (Howarth et al. 1986). Causes of free gas bloat are related to physiological disorders in the animal and include neural disorders, ruminal atony, and oesophageal obstruction (Blood et al. 1979).

This review is limited to a discussion of frothy bloat, specifically the type observed when ruminants confined to a feedlot are consuming high concentrate diets. Frothy legume bloat will be discussed when it is relevant to the aetiology of grain bloat. Frothy bloat is the result of a complex interaction between plant tissue, the microbial population, and the animal itself. As a result, research limited to the investigation of a single factor under in vivo or in vitro conditions often results in erroneous or incomplete conclusions.

2.3.1. Gas Production

Gas production, while being a natural product of microbial fermentation, is essential to the occurrence of bloat. While gas production alone does not cause frothy bloat, factors that increase the rate of fermentive gas production may contribute to the severity of it. Microbial activity, as measured by gas production, is reduced by the addition of ionophores to rumen contents (Katz et al. 1986). The ionophore monensin reduced in vitro gas production, from a legume diet, to a greater extent than did lasalocid. This corresponded to their respective efficacy in reducing the severity of legume bloat in cannulated cattle (Bartley et al. 1983; Katz et al. 1986). Poloxalene has little effect on microbial gas production (Katz et al. 1986) and is less effective in preventing grain bloat than legume bloat. These observations suggest that microbial gas production plays a major role in grain bloat.

The rate of fermentation of grain in the rumen, and hence gas production as well, is controlled by several factors. Perhaps the most significant is particle size. Small grain particles are more susceptible to hydrolysis by bacterial enzymes because surface area exposed to attack is greatly increased and cell wall integrity is somewhat compromised (Hale et al. 1980). Hironaka et al. (1973) found that one hour after feeding, in vitro gas production from the rumen contents of cattle fed a fine particle ration (geometric mean particle size of 388 μm) was 47% greater than gas production from cattle fed a coarse particle ration (particle size 715 μm). They also observed that the fine particle ration more readily produced

froth and bloat than the coarse particle ration. Other work supports these findings (Mead et al. 1944; Lindahl et al. 1957; Cheng and Hironaka 1973).

Processing methods that increase the availability of starch through gelatinization should also increase the rate of fermentation and gas production (Bartley et al. 1975). Mathison and Milligan (1984) reported a correlation (r = +0.99) between the rate of enzymatic glucose release in vitro and bloat observed in a feedlot trial. Kudo et al. (1985) indicate that the bloat causing potential of alfalfa might be reduced by selection for slower initial rate of digestion.

The integrity of plant cell walls has been suggested as a factor in legume bloat (Howarth et al. 1978; Lees et al. 1981). The rupture of cell walls provides microbial access to readily fermentable nutrients and facilitates the release of potential foaming agents (Howarth et al. 1986). Fay et al. (1980) showed that gas production from bloat-causing legumes was greater than from bloat-safe legumes, and that the relative order of gas production in six legume species was similar to the rates of dry matter degradation in vitro (Cheng et al. 1980) and in nylon bags (Howarth et al. 1982). Bloat-safe legumes have stronger cell walls than bloat- causing legumes (Howarth et al. 1978; Lees et al. 1981). Endosperm cell walls surrounding starch and protein in barley grain are composed primarily of beta-glucans (Bamforth 1982). The amount of beta-glucan in barley has been correlated to the rate of endosperm dissolution during germination

(Aastrup and Erdal 1980), and may be a factor in the rate of digestion and gas production in the rumen.

2.3.2. Foam Stability

Entrapment of gases in a stable foam or froth is of primary importance in the frothy bloat observed in cattle fed both legume and grain diets. Plant and microbial factors have been extensively investigated as causes of foam stability and more recently rumen flow kinetics have been considered (Howarth et al. 1986).

The role of soluble plant proteins in stabilizing foam has been elucidated by the work of several groups (McArthur et al. 1964; Stifel et al. 1968; McArthur and Miltimore 1969a,b; Jones and Lyttleton 1972; Jones et al. 1978). However, since the level of soluble proteins in the rumen of cattle fed alfalfa (Howarth et al. 1986) and clover (Jones and Lyttleton 1973) is low, it is unlikely that they are the exclusive foaming agents in causing bloat (Howarth et al. 1986). Furthermore, although soluble protein concentrations in rumen fluid are adequate to stabilize foams in vitro, there does not appear to be a relationship to the incidence of bloat in vivo (Majak et al. 1985).

Smith et al. (1953) and others used a grain diet high in protein (approximately 19%) to consistently produce bloat, but protein level may not have been the major factor since alfalfa meal made up 22% of the total diet. Also, Hironaka et al. (1973) was able to produce frothy rumen contents with a more typical diet of approximately 11%

protein. The presence of soluble protein in the rumen contents of grain bloated cattle has not been closely examined, but is not likely to be a major factor in grain bloat. However, under some conditions the possibility of soluble proteins contributing to foam stability cannot be ignored.

Lindahl et al. (1957) indicated that saponins in alfalfa might contribute to bloat. However, Majak et al. (1980) found that a low-saponin strain produced no significant increases in the incidence of bloat compared to that observed with a high-saponin strain. Grains do not contain saponins but do contain low amounts of lipids (Briggs 1978). However, plant lipids are generally considered to be anti-foaming agents which may promote coalescence of the stable bubbles of foam (Stifel et al. 1968; Howarth 1975).

2.3.3. Rumen Fluid Viscosity

High viscosity of rumen fluid has been reported to be related to grain bloat (Jacobsen et al. 1957; Gutierrez et al. 1961; Meyer and Bartley 1971; Cheng and Hironaka 1973). Viscosity prevents drainage of the fluid from between the gas bubbles, thereby creating frothiness (Howarth et al. 1986). The source of this viscosity is generally thought to be bacterial slime (Bartely et al. 1975). Bacterial slime can originate from the polysaccharide capsules of intact bacteria or from substances within the bacterial cell (Bartely et al. 1975). Ethanol precipitated slime increased with the onset and severity of bloat and was found to contain 33% protein, 29% ash, and

18% carbohydrate and nucleic acids (Gutierrez 1961). Cheng and Hironka (1973) found a relationship between viscosity and carbohydrate content of cell free rumen fluid, but did not believe that carbohydrate level was the primary factor influencing rumen fluid viscosity. The source of the carbohydrate was not determined. In a later paper by the same workers (Cheng et al. 1975) extracellular dextran from Streptococcus bovis was shown to be highly viscous, but only partially responsible for the viscosity of cell free rumen fluid. S. bovis has been implicated in grain bloat by other workers as well (Bartley et al. 1975). Lasalocid is more effective than monensin as an S. bovis inhibitor (Dennis et al. 1981), which corresponds to the relative effectiveness of these two ionophores in preventing grain bloat (Bartley et al. 1983).

Thus, the role of microbial carbohydrates in grain bloat cannot be ignored. Whether or not the source of carbohydrate in rumen fluid is of plant or microbial origin has not been determined. Plant carbohydrates, such as beta-glucans, could be at least partially responsible for the increased viscosity of rumen fluid, since extracts containing high levels of beta-glucan are highly viscous (Aastrup 1979a; Smith et al. 1980; Ullrich et al. 1986).

2.3.4. Surface Tension

Surface tension of cell free fluid is reported to be related to bloat by some (Meyer and Bartley 1972), but not by others (Elam and Davis 1962a,b). In theory, low surface tension of a fluid should

reduce the entrapment of gases. Poloxalene, a surfactant which lowers the surface tension of ruminal fluid, prevents the formation of foams and is effective in preventing legume bloat (Bartley et al. 1983; Katz et al. 1986).

2.3.5. Particle Dispersion

The dispersion of fine particles of chloroplast membranes in rumen fluid is thought to be a major contributor to legume bloat (Howarth et al. 1986). Majak et al. (1983,1985) found the concentration of such particles to be higher in frothy than in non-frothy rumen fluid on days when bloat was observed. The frothiness is likely caused by the particles increasing the viscosity of lamellar fluid, thus retarding the drainage of fluid between the bubbles (Howarth et al. 1986). Small feed particles from a grain diet may contribute to frothy bloat in a similar fashion (Howarth et al. 1986). Fine particle diets are known to increase the incidence of grain bloat (Cheng and Hironaka 1973; Hironaka et al. 1973). The precise mechanism by which the fine particle diets cause bloat is undetermined, but likely is due to a combination of increased rate of gas production, increased viscosity due to soluble carbohydrate, and dispersion of fine particles.

2.3.5. Animal Factors

The animal factors that have been considered in relation to frothy bloat include anatomical differences, rate of eating,

microbial population, rumen volume, rumen fluid dilution rate, saliva production and composition, and rumen motility (Bartley et al. 1975; Howarth et al. 1986). Rate of eating does not appear to be a major factor in susceptibility to bloat (Clark and Reid 1973) nor does rumen motility (Mendel and Boda 1961). Also, research has shown that anatomical or microbiological differences do not significantly account for the susceptibility to bloat that is observed in some animals (Howarth et al. 1986). The areas that do show promise are related to salivary flow, rumen fluid dilution rate, and rumen volume.

Saliva secretion can exceed 150 litres per day in adult dairy cows (Church 1976). Quantity of saliva varies with the nature of the diet; finely ground or pelleted rations stimulate only 20% as much total production as long hay diets (Bailey 1959 as cited by Church 1976). Mendel and Boda (1961) reported that rate of salivation was closely related to susceptibility to bloat. This is likely due to the effect saliva production has on rumen fluid dilution rate (rate of passage of rumen fluid) since saliva production can account for two-thirds of the daily volume of fluid passed from the rumen (Church 1976). The amount of fluid recycled from plasma through the rumen wall is unknown, but may have a significant affect on rumen fluid dilution rate (Church 1976).

Rumen volume was observed to be the major difference between two lines of cattle selected for high or low susceptibility to legume bloat. Lower rumen volume was observed in cattle selected for low

susceptibility to bloat (Cockrem et al. 1983 as cited by Majak et al. 1986). Majak et al. (1986), using marker techniques rather than direct measurement, reported no difference in rumen volume between bloating and non-bloating cattle. However, they did find significant differences in the rate of fluid passage with bloating cattle exhibiting only 50-75% of the flow measured in non-bloating cattle. Majak et al. (1986) also observed that chlorophyll content (a measure of chloroplast particles) to be significantly higher in the liquid phase of bloating than non-bloating cattle. Thus, a higher rate of fluid passage would conceivably "wash out" dispersed chloroplast particles thereby reducing susceptibility to bloat (Majak et al. 1986). Rumen fluid dilution rate is also a factor in grain bloat. Cheng et al. (1984) recommended the addition of 4% salt to the diet as a method of treating grain bloat. This level of sodium would stimulate water intake and saliva production and increase rumen fluid dilution rate thus reducing the concentration of small grain particles and any other foam stabilizing compounds.

2.3.6. Conclusions Concerning Bloat

Frothy bloat is likely the result of several factors occurring simultaneously rather than being wholly attributable to any one factor in particular. Soluble proteins and carbohydrates of plant or microbial origin no doubt contribute to rumen fluid viscosity and froth stability. In particular dextran, from S. Bovis, is highly viscous. Grain diets of fine particle size and rapidly digested plant

tissue increase the rate of gas production and rumen fluid viscosity when the particles are dispersed. Low saliva production, observed with cattle fed finely ground grain rations and lush, rapidly digested legumes, reduces the rate of fluid passage, which in turn increases the concentration of bloat causing factors in the rumen.

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3. EFFECT OF BETA-GLUCANS, PROCESSING METHOD AND OTHER FACTORS ON THE DIGESTION AND UTILIZATION OF BARLEY BY CATTLE.

3.1. MATERIALS AND METHODS

3.1.1. Experiment 1: Cattle feedlot trial

One hundred and twenty yearling steers were used in a 6 X 2 X 2 factorial design to assess the effect of beta-glucan content processing method, and barn type on feedlot performance and carcass quality.

Feed preparation

Barley grain was selected on the basis of beta-glucan content from six different sources. Dry rolled (DR) barley was prepared by processing the grain through a Roskamp roller mill (Roskamp Mfg. Inc. Cedar Falls, Iowa) equipped with corrugated rollers (76 cm in length). Steam-rolled (SR) barley was prepared by adding steam (68.9 KPa) to barley in a 1359 litre chamber, open to the atmosphere, for a period of 20 min before rolling. When the temperature of the grain rose to 100°C the steam valves were closed. This occured within approximately 12 min at the top of the chamber, and 16 min at the bottom of the chamber.

Barley from each source, in the DR or SR form, was used as the major ingredient in the concentrate portion (Table 3.1) of 12 experimental diets. Chemical composition of the concentrates is presented in Table 3.2. The concentrates were significantly different in crude protein, beta-glucan, starch, potassium, sulphur, and

selenium content. Since the ingredient composition of the diets was identical, these differences can be attributed to the composition of the barley rather than the supplements. Except for potassium, managese, and selenium, all concentrates met or exceeded published (National Academy of Sciences, 1984) minium dietary standards for the class of cattle used in this experiment. The theoretical deficiences in potassium, manganese and selenium were minor and did not likely influence the results of this experiment. Mixed grass-legume hay of medium quality (12.0% protein, 36.8% acid detergent fiber, 1.13% calcium, and 0.17 % phosphorus on a dry matter (DM) basis) was processed through a 7.6 cm screen in a tub grinder (Model 390, Sperry New Holland, New Holland, Pa.) and fed as the roughage source.

Animal management

One hundred and twenty yearling crossbred steers were purchased and delivered to the feedlot over a 6 day period. Prior to commencement of the trial all steers were ear tagged and vaccinated for Blackleg and Malignant edma (Bay Vet Division, Miles Laboratory Inc., Shawnee, Kan.). A 2 mL intramuscular injection of vitamin ADE solution (Dominion Veterinary Laboratories, Winnepeg, Man.) provided 1,000,000 IU of vitamin A, 150,000 IU of vitamin D, and 100 IU of vitamin E. A growth promotant (Ralgro; International Minerals and Chemical Corp., Terre Haute, Ind.) was also administered and 22 steers were dehorned.

At the start of the trial steers were weighed on three consecutive days. Weights were taken before feeding and after water

was withheld for 16 h. Based on the first two weights obtained, steers were ranked in ascending order. The ranks were divided into five groups of 24 animals each. Animals from each weight group were then allocated at random to one of 24 partially covered pens (4 x 8 m) located in one of two types barns . Both types were of the open front shed design. One measured 4 m to the front of the roof while the other type measured 6 m to the front of the roof.

Over the 7 d preceeding the start of the trial all animals were changed from a diet of 100% chopped hay, offered ad libitum, to a diet of 17% chopped hay plus 83% concentrate. This amounted to 1.0 and 5.0 kg animal^{-1}d^{-1} of hay and concentrate, respectively. After the trial started the amount of hay allotted remained at 1.0 kg animal^{-1} d^{-1} (as fed basis) and the concentrate was fed ad libitum. This resulted in total ration that was 90.4 % concentrate and 9.6 % hay for the total feeding period.

The animals were weighed at 14 d intervals throughout the trial. Final weights were taken on two consecutive days. Marketing, based on weight, occurred on d 103, 110 and 117 of the trial. At the slaughter house incidence of liver condemnation due to abscess was recorded. Carcass data were collected by Agriculture Canada personnel (Beef Carcass Appraisal Program).

3.1.2 Experiment 2: Degradability of Barley Dry Matter, Starch and Beta-glucan

In vitro

The rate of enzymatic starch hydrolysis in whole, DR and SR barley was determined by the method of Mathison and Milligan (1984). In this procedure, adapted from McRae and Armstrong (1968), amyloglucosidase enzyme (Aspergillus niger, No. A3514, Sigma Chem. Co. Ltd., St Louis, Mo.) is used to hydrolyze starch. The amount of glucose released is determined at various intervals of incubation using a standard hexokinase kit (NO. 115-A, Sigma Diagnostics, St. Louis, Mo.). Details of the procedure are provided in Appendix 1.

In situ -

Two one-year old rumen fistulated steers were used in a factorial design to determine dry matter (DM), starch, and beta-glucan disappearance from barley incubated in situ. The barley used was the same as that fed in the animal feeding trial so that processing methods (2) and beta-glucan content (6) were the factors examined. Diets of both steers were 90% concentrate (DR, barley lot 2) and 10% chopped hay (as for animal feeding trial) fed ad libitum. Dry matter disappearance was determined after 0, 8, and 24 h incubation and starch and beta-glucan disappearance were determined after 0 and 8 h incubation.

Bags (7.0 x 11.0 cm) used for incubation of barley were made from nylon (Phentex PE300 pore size 48 μm, B and SH Thompson Co. Ltd., Toronto, Ont.). The bags were folded along each edge and double stitched. Steam-rolled and DR barley was air dried for 48 h prior to grinding through a 2 mm screen. A portion of each sample was used for

60°C dry matter determination. Approximately 5 g of air dry sample was placed in each oven (60°C) dried bag. The top of each bag was then tied off with fishing line.

Twelve nylon bags containing barley were placed in a polyester mesh bag (lingerie bag, 25 x 30 cm, mesh size 3 mm) which was inserted into the rumen of each steer at 1600 h each day. The mesh bag had a draw string (25 cm long) to which two leads were attached. The first lead (50 cm long) was attached to the rumen cannula. The second lead (20 cm long) was attached to a weight that remained at the bottom of the ventral sac of the rumen. This arrangement held the mesh bag within the liquid phase of the rumen. At 800 h of the following day, twelve additional nylon bags containing barley were placed in the mesh bag. At 1600 h that day the mesh bag, containing all 24 nylon bags, was removed from each steer and briefly rinsed under cold tap water to remove large adherent particles. The nylon bags were then removed from the mesh bag and placed in a mechanical washer (De Boer et al. 1987). After washing for 20 min nylon bags containing barley residues were dried at 60°C for 48 h and then weighed. The dry residue from four replications was combined for each steer and used for starch and beta-glucan determination. Bags used for 0 h disappearance calculations were treated in the same manner but were not suspended in the rumen.

3.1.3 Experiment 3: Digestibility Trial

The apparent total tract digestibility of DM, protein, beta-glucan

and starch was determined on four samples of barley that were selected on the basis of volume weight (VW). Digestibility was determined at the Ruminant Feed Evaluation Unit (University of Alberta, Edmonton, Alta.) using standard total collection procedures. Barley made up 98.3% of the diets (Table 3.3), each of which were fed to five one-year old steers. Water and trace mineralized salt were available at all times.

During the first 17 d steers were kept in individual floor stalls (0.99 x 1.7 m) equipped with rubber floor mats. During this period steers were adapted to the grain diets. Steers were then moved to metabolism crates (0.98 x 2.44 m). Diets were fed at two times their calculated maintenance level of intake (based on net energy requirements) for 10 d. During the following 8 d feces were collected and digestibility was determined.

3.1.4. Chemical and Physical Analysis

Samples of whole barley were collected prior to weekly processing at the feedmill and pooled to form five composite samples of each. Dry rolled and steam rolled samples of each barley lot were collected after processing. Concentrates were sampled bi-weekly with a grain sample probe from wooden boxes (1.2 X 1.2 m) that were used for storage prior to feeding. Samples of hay were taken at random by hand from a large pile of chopped material that was located in a weather proof storage building.

Moisture content was determined at 100°C according to

Association of Official Analytical Chemisits (AOAC) (1984) procedures. Acid detergent fiber (ADF), neutral detergent fiber (NDF) and acid detergent insoluble nitrogen (ADIN) were determined by the method of Goering and Van Soest (1970). Volume weight (kg hL^{-1}) was calculated by multiplying the weight (g) of whole grain in a 302 mL container by 0.33113. For protein and phosphorus samples were digested using the Kjeldahl procedure (method 7.021, AOAC 1984) and colorimetrically determined on a Technicon Auto Analyzer II (method 7.025, AOAC 1984). For other minerals samples were digested in a nitric (4):perchloric (1) acid mixture. Selenium was determined on a Kontron Spectrofluorometer (Research Instrument International, San Diago, Calif.) according to AOAC (1984) method 3.107. Sulfur was determined by infrared analysis of sulfur dioxide released on total ignition using a LECO Model SC-132 (LECO Corp., St. Joseph, Mich.). Calcium, magnesium, potassium, copper, manganese, and zinc were determined by emission spectroscopy using an Inductively Coupled Plasma (ICP) (Applied Research Laboratories Inc., Sunland, Calif.). All of these analyses were conducted at the Agricultural Soil and Animal Nutrition Laboratory, Alberta Agriculture, Edmonton, Alberta.

Beta-glucan content was determined using an enzymatic procedure. Purified beta-glucanase was obtained by heating (70°C), centrifuging (7000 g), and dialyzing (16 h) a commercial cellulase preparation (Penicillium funiculosum, No. C0901, Sigma Chemical Co. Ltd, St. Louis, Mo.) according to the method of Bamforth (1983). The purified enzyme did not exhibit amyloglucosidase activity when

incubated with soluble potato starch (No. 5-2630, Sigma Chemical Co. Ltd, St. Louis, Mo.) but did hydrolyze pure barley beta-glucan (No. G6513, Sigma Chemical Co. Ltd, St. Louis, Mo.). Beta-glucan measurement was then conducted by a modification of the procedure reported by Henry (1984). Samples were boiled in ethanol to inactivate endogenous enzymes and remove soluble sugars. Incubation in buffer with the purified beta-glucanase degraded beta-glucan to glucose which was subsequently determined with a standard hexokinase kit (No. 115-A, Sigma Diagnostics, St. Louis, Mo.).

Starch was determined on barley and concentrates using a modification of the procedure of Salmonsson et al. (1984). Samples were first heated (90°C) with a thermostabel alpha-amylase (Termamyl 60L, Nova Industries A/S, Bagsvaerd, Denmark) to gelatinize and degrade starch to lower oligosaccharides. Subsequent incubation with amyloglucosidase in a buffer solution completed the hydrolysis to glucose which was determined as described previously.

Details of beta-glucan and starch determination are provided in Appendix 1.

3.1.5. Statistical Analyses

A Student's "t" test (Steele and Torrie 1980) was used to compare the chemical components of DR and SR barley. The Categorical Response Model Procedure (Grizzle et al. 1969) was used to analyze the number of animals with liver abscesses and the carcass grade data. The General Linear Model (GLM) procedure was used to analyze all other

data. These procedures are of the Statistical Analysis System (SAS Institute Inc., Box 800, Cary, N.C. 27511). The following models describe the sources of variation considered in the experiments:

Starch hydrolysis: $Y_{ijm} = m + A_i + B_j + AB_{ij} + E_{ijm}$

In situ degradation: $Y_{ijkm} = m + A_i + B_j + C_k + AB_{ij} + E_{ijkm}$

ADG: $Y_{ijlm} = m + A_i + B_j + D_l + AB_{ij} + AD_{il} + BD_{jl} + ABD_{ijl} + E_{ijlm}$

DMI and DM:G: $Y_{ijlm} = m + A_i + B_j + D_l + AB_{ij} + AD_{il} + BD_{jl} + E_{ijlm}$

where:

ADG = average daily gain, individual animal basis

DM:G = dry matter per unit gain, pen basis

DMI = dry matter intake, pen basis

Y_i, Y_{ijk} or Y_{ijl} = the individual observation for a given dependant variable,

m = the overall mean

A_i = the effect of the i^{th} lot of barley, i = 1 to 6

B_j = the effect of the j^{th} processing method, j = 1 and 2

C_k = the effect of the k^{th} steer, k = 1 and 2

D_l = the effect of the l^{th} barn type, l = 1 and 2

AB_{ij}, AD_{il}, BD_{jl} and ABD_{ijl} = the interaction term, and

E_{ijm}, E_{ijkm} or E_{ijlm} = the residual.

All main effects were considered fixed.

3.2. RESULTS

3.2.1. Composition of Barley

Chemical composition of the six lots of barley used in exp. 1 and 2 is provided in Table 3.4. No attempt was made to remove dockage from barley prior to feeding or analysis. Differences ($P < 0.05$) were apparent in all components except moisture.

Correlation coefficients between the various chemical components of the six lots of barley are provided in Table 3.5. beta-glucan content was positively correlated with starch and VW and negatively with ADF, NDF, and protein. However, only the correlation with VW was significant ($P < 0.05$). Starch was significantly ($P < 0.05$) correlated with ADF ($r = -0.93$) and NDF ($r = -0.93$). The correlation between starch and VW was positive ($r = 0.71$) but non-significant ($P = 0.12$). Protein in the barleys was not significantly correlated with any of the other components.

Processing method had no effect on beta-glucan or starch content of barley (Table 3.6). Steam rolling did significantly ($P = 0.01$) increase acid detergent insoluble nitrogen (ADIN) and ADF values relative to DR.

3.2.2. Experiment 1: Cattle feedlot Trial

Feedlot performance data are reported in Table 3.7. One animal from barley lot number 5 (SR) died from bloat 62 d after the trial was started. Feed intake data was corrected for this.

Average daily gains (1.49 to 1.56 kg d^{-1}) were acceptable for a trial of this nature. There were no significant ($P < 0.05$) differences observed between barley lot or processing method for any

of the parameters measured. It is noteworthy that the significant differences in protein content of the concentrates did not have an effect on performance. This is evidence that protein requirments were met for all cattle. Interactions between barley lot, processing method and barn type were not reported due to lack of statistical significance.

Carcass traits and the incidence of liver abscesses are reported in Table 3.8. The grades and yields achieved were acceptable although the proportion of cattle grading A3 was higher than normal. The cutability estimate for cattle fed barley lot number 1 was significantly ($P < 0.05$) lower than for cattle fed other barley. Dressing percentage for steers fed DR was higher ($P = 0.03$) than for steers fed SR. No other significant differences were observed between barley lots or processing methods.

Several correlations between the chemical compositon of the barley and feedlot performance were significant ($P < 0.05$) (Table 3.5). Dry matter intake was correlated positively with NDF ($r = 0.85$) and negatively with VW ($r = -0.85$). Dry matter to gain ratio (DM:G) was correlated negatively with starch content ($r = -0.83$) and VW ($r = -0.81$) and positively with ADF ($r = 0.95$) and NDF ($r = 0.85$). The correlation between beta-glucan and DM:G ($r = -0.79$) exhibited a trend towards significance ($P < 0.10$). None of the components of barley measured in this experiment exhibited a trend towards significant correlations with ADG, and thus these correlations were not reported in Table 3.5.

3.2.3. Experiment 2: Degradability of DM, Starch and Beta-glucan

Results for the amount of glucose released from alph-linked polymers during in vitro incubation with amyloglucosidase are presented in Table 3.9. Differences ($P < 0.05$) were observed between barley lots at all three times. After 1 and 2 h significantly ($P < 0.05$) more glucose was released from SR barley than from DR or non-processed barley. The effect of interactions between barley lot and processing method was significant ($P < 0.05$) after 2 and 27 h and approached significance ($P = 0.06$) after 1 h.

No significant ($P < 0.05$) correlations existed between the amount of glucose released after 2 h in vitro incubation and any component of barley (Table 3.5). Likewise there were no significant correlations ($P > 0.05$) with the in situ degradability or feedlot performance results.

Results of the in situ degradability experiment are presented in Table 3.10. Differences ($P < 0.05$) in DM disappearance (DMD) were observed between the six lots of barley at all times in situ. Differences in beta-glucan disappearance were significant ($P < 0.05$) between barley lots after 8 h in situ. Differences ($P < 0.01$) in starch disappearance were apparent after 0 and 8 h in situ.

Dry matter, beta-glucan and starch disappearance from SR was less ($P < 0.01$) than from DR at all times. This was in contrast to the results obtained for the amount of glucose released after 1 and 2 h of in vitro incubation with amyloglucosidase. For DM disappearance

the interaction between barley lot and processing method was significant ($P < 0.01$) after 0 and 8 h in situ. For starch disappearance the interaction was only significant ($P<0.01$) after 8 h in situ.

In situ disappearance of DM, beta-glucan and starch were significantly ($P < 0.05$) correlated with a number of the other parameters measured (Table 3.5). Dry matter disappearance after 8 h in situ was correlated positively with starch content ($r = 0.83$) and VW ($r = 0.91$) and negatively with protein content ($r = -0.85$). After 24 h in situ, DM disappearance was negatively correlated with ADF ($r = -0.93$) and NDF ($r = -0.91$). Starch content ($r = 0.96$) and VW ($r = 0.87$) showed strong correlations with DMD. Starch disappearance after 8 h in situ was negatively correlated ($r = -0.92$) with protein content. beta-glucan disappearance was correlated positively with VW ($r = 0.88$) and negatively with NDF ($r = -0.89$). Dry matter intake was negatively correlated with DM disappearance after 24 h in situ ($r = -0.86$) and beta-glucan disappearance after 8 h in situ ($r = -0.95$). Dry matter to gain ratio was also correlated with these same measurements ($r = -0.91$ and -0.83 respectively).

Simple regression equations for the parameters exhibiting significant ($P < 0.05$) correlations with DMI and DM:G (dependant variables) were developed (Table 3.11). For DMI the equation that accounts for the greatest amount of variation ($R^2 = 0.91$) contained the 8 h beta-glucan disappearance value as the independant variable. For DM:G the best equation ($R^2 = 0.90$) contained ADF content as the

independant variable.

3.2.4.Experiment 3: Digestibility trial

The compositon and apparent digestibilities of components of the four barleys is presented in Table 3.12. There were no differences in the digestibility of DM, protein, starch, beta-glucan or NDF between barleys of different volume weight. The mean value for digestibility of the beta-glucan fraction is high (98.6%) and similar to the value for the starch fraction (98.1%).

3.3. DISCUSSION

3.3.1 Barley Quality

Volume weight, protein, and moisture content of the test samples were within the normal range for barley grown in Alberta (Suleiman 1987). The mean beta-glucan content of the six barleys was 4.2 % and is similar to the values reported by Anderson et al. (1978) for Western Canadian barley (3.77 to 5.62 %). Newman (1986) reports that hulless, waxy barley may contain up to 13.5 % total beta-glucan and that the short awn genotype may also have a high beta-glucan content.

The mean starch content (62.0%) is almost identical to the value (61.9%) reported by Sibbald and Price (1976) for 40 samples of Canadian barley representing 17 cultivars. In contrast, Bhatty et al. (1974) reported mean starch content of 50.0% in 29 cultivars of Western Canadian barley.

3.3.2 Animal Performance

The cutability estimate for steers from barley lot 1 were lower ($P = 0.02$) than from other treatments but the reason for this is not apparent. The lack of any other significant differences in major carcass traits and ADG between cattle fed different lots of barley is in agreement with other work (Mathison and Milligan 1984; Grimson et al. 1987). However, Hinman (1978) reported that cattle fed light (52.4 kg hL^{-1}) barley did gain significantly slower compared to cattle fed barley weighing greater than 56.1 kg hL^{-1}.

Differences in DM:G between barley lots were not significant ($P = 0.17$) which is in agreement with Mathison and Milligan (1984). Grimson et al. (1987) reported that significantly ($P < 0.001$) more DM:G was required when steers were fed light (47.8 kg hL) compared to medium (55.6kg hL^{-1}) or heavy (66.6 kg hL^{-1}) barley. In our work the correlation between VW and DM:G was significant ($r = -0.81$). The regression equation developed (Table 3.11) indicates that DM:G decreases 0.03 units for each kg hL^{-1} increase in VW ($P = 0.05$, $R^2 = 0.66$). Starch content was also correlated with DM:G ($r = -0.83$). The regression equation developed indicated that the amount of dry matter required for gain decreased 0.05 units for each one percentage unit increase in starch ($P = 0.04$, $R^2 = 0.69$). Since starch is highly digestible (Waldo 1973; Rooney and Pflugfelder 1986), this relationship is not surprising.

The beta-glucan content of the barleys used in this experiment

appears to have had little effect on the digestion and utilization of barley. The correlation between beta-glucan and dry matter disappearance (DMD) from nylon bags (Table 3.5) is positive rather than negative. The digestibility of beta-glucan is as high as the digestibility of starch (Table 3.12). The regression equation developed (Table 3.11) indicates that DM:G decreased 0.36 units for each one percentage unit increase in beta-glucan content ($P = 0.06$, $R^2 = 0.62$). This is in contrast to results with poultry where beta-glucan content is considered an impairment to the digestion and utilization of barley based diets (Gohl et al. 1978; Hesselman et al. 1981,1982; Cambell et al. 1987). beta-glucans are also thought by some to be detrimental to performance when barley is fed to young swine (Froseth et al. 1981; Honeyfield et al. 1983; Taylor et al. 1985). The difference between monogastric and ruminant animals is likely the presence of considerable beta-glucanase activity in the microbial population of the rumen. Teather and Wood (1982) showed that six common species of rumen microorganisms exhibit mixed-linkage beta-glucanase activity.

A high beta-glucan content is known to reduce the rate of starch hydrolysis during germination (Aastrup and Erdal 1980). This is in agreement with our observation that the in vitro release of glucose from starch was negatively correlated with beta-glucan content (Table 3.5). However, in the multi-enzyme system of the rumen, beta-glucan content does not reduce the rate of starch disappearance. Considering the high digestibility and rapid in situ disappearance of beta-glucan

in these trials, higher levels of beta-glucan in barley would not likely have a negative effect on the value of barley for cattle. Thus beta-glucans, present in endosperm cell walls, do not appear to be a limiting factor to digestion of barley by cattle.

Acid and neutral detergent fiber content of barley were correlated ($P < 0.05$) with DM disappearance in situ, DMI, and DM:G. The regression equations developed (Table 3.11) indicated that ADF accounts for a greater amount of variation in DM:G ($R^2 = 0.90$) than does NDF ($R^2 = 0.73$) or VW ($R^2 = 0.66$). The ADF equation indicated that DM:G increases 0.13 units for each one percentage unit increase in ADF ($P < 0.01$). The best predictor of DMI was VW ($R^2 = 0.73$, $P = 0.03$) but NDF was also good ($R^2 = 0.72$, $P = 0.03$).

To test the application of VW and ADF equations on a broader base, our data was pooled with the data of Mathison and Milligan (1984) and Grimson et al. (1987). Values for VW, ADF, DMI, and DM:G were standardized to a common mean using the PROC STANDARD procedure of SAS. In the regressions developed using this pooled data VW was not as good as ADF for predictiong DMI and DM:G. The R^2 values for the VW equation were 0.16 (DM:G) and 0.36 (DMI) compared to 0.28 (DM:G) and 0.54 (DMI) for the ADF equations. Thus, it appears that the ADF content in barley, although more difficult to measure than VW, may be the best indicator of barley quality for cattle.

Although there were differences between barley lots in the amount of glucose released at various times of in vitro incubation with amyloglucosidase (Table 3.9), the results did not correlate with any

of the in situ or feedlot performance data (Table 3.5). It is surprising that poor correlations with starch content of barley (r = 0.04) and starch dissapearance in situ (r = 0.07) were evident. This suggests that an amyloglucosidase preparation alone is not useful for in vitro evaluation of the quality of barley for cattle. A multi-enzyme preparation including a microbial protease may improve this technique. However, the in situ disappearance of starch was also poorly correlated with feedlot performance of cattle.

The in situ technique, although time consuming, did provide some good correlations with feedlot performance. The best regression equation indicates that DM:G decreases 0.09 units for every onepercentage unit increase of in situ DM disappearance at 24 h ($P = 0.01$, $R^2 = 0.83$). Since this equation accounts for more variation in DM:G than the starch or beta-glucan disappearance equations, there is no advantage to determining the content of these components in barley or residues. Interestingly the best in situ factor for predicting DMI was the disappearance of beta-glucan at 8 h ($P < 0.01$, $R^2 = 0.91$).

3.3.2. Processing Method

The difference between SR and DR in ADIN and ADF content (Table 3.3) is in agreement with the results of Mathison and Milligan (1984). Steam rolling was expected to gelatinize barley starch making it more accessible to enzymatic attack (Waldo 1973; Hale 1980; Galyean et al. 1981) and the results for amount of glucose released in vitro (Table

3.9) are in agreement with this expectation. However, results from the in situ trial are not in agrement with the observations of in vitro glucose release. In situ more DM, starch and beta-glucan disappeared from DR than from SR. The reason for this discrepancy between techniques is not clear. However, although both SR and DR were air dried to the same moisture content prior to grinding and placing in bags, DR barley may have contained more small particles than SR. Some of these particles may have disappeared from the bag without need for microbial degradation. The 0 h disappearance losses of DM were higher than expected but, not unlike the values reported by other workers for this technique. De Boer et al. (1987) using identical (48 μm pore size) nylon bags reported DM disappearance of ground (1 mm screen) barley to be 67.2 and 81.7 % after 0 and 8 h in situ respectively. Lindberg (1981) reported DM disappearance of 40.0 and 78.4 % after 2 and 12 h in situ respectively when nylon bags of 10 μm pore size were used and barley was ground through a 1 mm screen.

The lack of improvement in animal performance from steam rolling is in agreement with other work (Nicholson 1969; Mathison and Milligan 1984; Grimson et al. 1987). As mentioned steam treatment followed by rolling should make the starch fraction more accessible to enzymatic degradation. However, barley starch is highly digestible and does not respond to gelatinization to the same degree that corn or sorghum starch do (Rooney and Plfugfelder 1986). Also, excessive amounts of heat and pressure may have reduced the digestibility of

starch by the formation of dextrins (Rooney and Pflugfelder 1986) or by retrogradation (French 1973; Rooney and Pflugfelder 1986). It is also possible that the increased particle size of SR negates the benefits of gelatinization. Larger particle size was believed responsible for a 12 to 14% increase in DM:G required with steam-rolled compared to ground barley (Hironaka (1979). Some of the smaller particles present in DR may quickly escape from the rumen and be digested in the small intestine. Small particles have a higher digestibility in the small intestine than do large particles Owens et al. (1986). Also, Owens et al. (1986) calculated that starch digested in the small intestine provides 42% more net energy than starch digested in the rumen. Shifting starch digestion from the rumen would also reduce the concentration of organic acids and improve digestibility of the fiber fraction of the diet (Orskov 1986).

Improvement in dressing percentage in cattle fed DR has not been previously reported. The reason for the improvement in the present experiment is not apparent. Other carcass characteristics were not affected by the method of processing which is in agreement with previous work (Mathison and Milligan 1984; Grimson et al. 1987). Although not significant, there were fewer liver abscesses from the SR treatment. Grimson et al. (1987) found fewer ($P = 0.02$) liver abscesses in cattle fed steam flaked barley. Liver abscesses in cattle fed finishing diets are related to acidosis and rumenitis (Brent 1976) and are responsible for reduced performance of feedlot cattle (Rust et al. 1980). In our trial feedlot performance did not

appear to be adversely affected by the presence of liver abscesses, but even livers with very small abscesses were considered abscessed in the analysis of our data.

In summary, beta-glucans in barley are highly digestible, are positively correlated with VW, and have no adverse affects on digestion and utilization of barley in cattle. Volume weight and ADF have value as predictors of barley quality for cattle. The practice of steam rolling or flaking of barley does not, relative to dry rolling, improve the performance or carcass characteristics of finishing cattle in a feedlot.

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Table 3.1. Composition (as-fed basis) of concentrate used in feedlot diets

Ingredient	Amount
Barley	90.50
Canola meal	5.50
Wet molasses	2.00
Ground limestone	1.40
Trace mineralized salt[1]	0.35
Vitamin premix[2]	0.25

[1]Contained the following per kg: 940 g sodium chloride, 100 mg iodine, 40 mg cobalt, 7500 mg zinc, 2500 mg copper, 3500 mg manganese and 25 mg selenium.
[2]Contained the following per g: 2000, 200, and 2 IU of vitamin A, D, and E respectively.

Table 3.2. Least square means of various chemical components of concentrates by barley lot and processing method

	Barley lot number								Processing method			
	1	2	3	4	5	6	SEM[1]	Probability	SR	DR	SEM[1]	Probability
Moisture (% air dry)	12.8	13.0	13.2	13.9	12.9	12.9	0.90	0.97	14.0	12.3	0.52	0.03
Crude Protein (% DM)	12.7^{b}	15.2^{a}	14.4^{ab}	15.0^{a}	14.2^{ab}	11.2^{c}	0.51	<0.01	14.2	13.4	0.29	0.06
Beta-glucan (% DM)	3.3^{c}	3.5^{bc}	3.8^{b}	3.7^{bc}	4.3^{a}	4.4^{a}	0.12	<0.01	3.9	3.8	0.07	0.31
Starch (% DM)	56.7^{b}	57.1^{ab}	58.5^{ab}	53.0^{c}	57.8^{ab}	60.4^{a}	0.88	<0.01	57.2	57.3	0.50	0.91
Calcium (% DM)	0.41	0.50	0.52	0.53	0.55	0.50	0.06	0.75	0.54	0.47	0.04	0.22
Phosphorus (% DM)	0.39	0.43	0.38	0.44	0.46	0.40	0.02	0.03	0.42	0.41	0.01	0.31
Magnesium (% DM)	0.16	0.18	0.17	0.17	0.17	0.17	0.01	0.22	0.17	0.17	0.01	0.31
Potassium (% DM)	0.54^{c}	0.49^{d}	0.60^{b}	0.66^{a}	0.54^{c}	0.58^{bc}	0.02	<0.01	0.57	0.56	0.01	0.29
Sulphur (% DM)	0.22^{a}	0.24^{a}	0.23^{a}	0.23^{a}	0.21^{a}	0.17^{b}	0.01	<0.01	0.22	0.21	0.01	0.07
Copper (mg kg^{-1}DM)	10.1	12.7	11.7	11.1	14.0	13.5	1.29	0.27	12.4	11.9	0.74	0.64
Manganese (mg kg^{-1}DM)	21.7	26.1	25.4	29.5	27.5	23.8	2.16	0.20	26.8	24.5	1.27	0.22
Zinc (mg kg^{-1}DM)	54.6	61.7	57.1	53.8	70.2	55.9	5.42	0.33	59.1	58.7	3.22	0.92
Selenium (mg kg^{-1}DM)	0.31^{b}	0.25^{b}	0.18^{c}	0.15^{c}	0.85^{a}	0.28^{b}	0.02	<0.01	0.35	0.32	0.01	0.07

[1]Standard error of the mean was based on six observations per barley lot and 18 observations per processing method.

Table 3.3. Composition (% as-fed basis) of diets used for exp. 3

Ingredient	Amount
Barley, dry rolled	98.3
Ground limestone	1.10
Trace mineralized salt[1]	0.35
Vitamin premix[2]	0.25

[1]Contained the following per kg: 940 g sodium chloride, 100 mg iodine, 40 mg cobalt, 7500 mg zinc, 2500 mg copper, 3500 mg manganese and 25 mg selenium.
[2]Contained the following per g: 2000, 200, and 2 IU of vitamin A, D, and E respectively.

Table 3.4 Means for various chemical components of barley dry matter[1] prior to processing

Item	Beta-Glucans (%)	Starch (%)	Protein (%)	ADF[2] (%)	NDF[3] (%)	VW[4] (kg hL^{-1})	Moisture (%)
Barley lot no.							
1	3.5^{c}	61.2^{b}	11.5^{b}	8.5^{b}	18.4^{b}	58.9^{c}	12.0
2	3.9^{b}	61.8^{b}	13.5^{a}	7.1^{c}	18.6^{b}	56.9^{d}	11.7
3	4.1^{b}	62.0^{b}	12.9^{a}	6.7^{d}	17.2^{b,c}	66.2^{b}	11.8
4	4.1^{b}	56.5^{c}	13.2^{a}	9.7^{a}	22.1^{a}	59.5^{c}	11.5
5	4.6^{a}	64.9^{a}	12.3^{a,b}	5.7^{e}	14.4^{d}	67.2^{b}	11.8
6	4.8^{a}	65.6^{a}	9.1^{c}	6.3^{d}	16.5^{c}	70.5^{a}	11.5
SEM[5]	0.07	0.81	0.31	0.15	0.47	0.60	0.19
Probability	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.38

[1] All values except VW and moisture are on dry matter basis.
[2] Acid detergent fiber.
[3] Neutral detergent fiber.
[4] Volume weight.
[5] Standard error of the mean based on five samples per lot except for NDF (four per lot).

Table 3.5. Correlation coefficients between chemical components of barley, in vitro and in situ results, and feedlot performance

	BG[1]	Starch	Protein	ADF[2]	NDF[3]	VW[4]	Glu2h[5]	DMD8[6]	DMD24[7]	BGD8[8]	STRD8[9]	DMI[10]	DM:G[11]
BG[1]	1.00	0.59	-0.50	-0.62	-0.52	0.85*	-0.54	0.74T	0.72	0.66	0.41	-0.50	-0.79T
Starch		1.00	-0.61	-0.93*	-0.93*	0.71	0.04	0.83*	0.96*	0.78T	0.32	-0.75T	-0.83*
Protein			1.00	0.32	0.39	-0.65	-0.07	-0.85*	-0.63	-0.46	-0.92*	0.47	0.30
ADF[2]				1.00	0.93*	-0.69	0.13	-0.71	-0.93*	-0.79T	-0.06	0.75T	0.95*
NDF[3]					1.00	-0.69	0.15	-0.69	-0.91*	-0.89*	-0.09	0.85*	0.85*
VW[4]						1.00	-.59	0.91*	0.87*	0.88*	0.59	-0.85*	0.81*
Glu2h[5]							1.00	-0.22	-0.21	-0.53	-0.07	0.45	0.40
DMD8[6]								1.00	0.92*	0.76t	0.74T	-0.78T	-0.73T
DMD24[7]									1.00	0.87*	0.41	-0.86*	-0.91*
BGD8[8]										1.00	0.28	-0.95*	-0.83*
STARD8[9]											1.00	-0.34	-0.10
DMI[10]												1.00	0.76T

[1]Beta-glucan (% dry matter).
[2]Acid detergent fiber (% dry matter).
[3]Neutral detergent fiber (% dry matter).
[4]Volume weight (kg hL^{-1}, air dry).
[5]Glucose released after 2 h in vitro incubation (mg g^{-1}).
[6]Percent dry matter disappearance from nylon bags after 8 h in the rumen.
[7]Percent dry matter disappearance from nylon bags after 24 h in the rumen.
[8]Percent beta-glucan disappearance from nylon bags after 8 h in the rumen.
[9]Percent starch disappearance from nylon bags after 8 h in the rumen.
[10]Daily dry matter intake of feedlot steers (kg $steer^{-1}$).
[11]Amount of dry matter required per unit of gain.
*$P < 0.05$, T$P < 0.10$

Table 3.6. Effects of processing methods on chemical components of barley dry matter

Item	Steam Rolled	Dry Rolled	SEM[1]	Probability
BG[2] (%)	4.4	4.4	0.18	1.00
Starch (%)	54.9	55.7	1.05	0.33
ADIN[3] (%)	0.26	0.08	0.019	0.01
ADF[4] (%)	8.8	7.0	.54	0.01

[1]Standard error of the mean was based on 12 samples per processing method, two from each barley lot.
[2]Beta-glucan.
[3]Acid detergent insoluble nitrogen.
[4]Acid detergent fiber.

Table 3.7. Least squares means for feedlot performance of yearling steers by barley lot and processing method

Item	Initial[1] weight (kg)	Average daily gain[1] (kg)		Dry matter intake[2] (kg)		DM:G[2]	
		0-34 d	overall	0-34 d	overall	0-34 d	overall
Barley lot no.							
1	342.2	1.46	1.49	6.79	9.42	4.72	6.35
2	340.9	1.64	1.57	6.94	9.72	4.34	6.12
3	341.8	1.42	1.53	6.78	9.09	4.92	5.97
4	343.0	1.67	1.55	7.21	9.77	4.43	6.34
5	342.1	1.57	1.56	6.84	9.11	4.35	5.85
6	339.9	1.55	1.56	6.84	9.19	4.47	5.92
SEM	5.12	0.10	0.05	0.18	0.24	0.33	0.14
Probability	1.00	0.42	0.81	0.60	0.29	0.74	0.17
Processing methods							
Steam rolled	341.9	1.60	1.53	6.94	9.35	4.41	6.04
Dry rolled	341.4	1.50	1.56	6.86	9.41	4.64	6.16
SEM	2.90	0.06	0.03	0.10	0.14	0.19	0.08
Probability	0.89	0.86	0.33	0.59	0.78	0.42	0.33

[1]Means for barley lots were based on 20 animals per treatment except for barley lot no. 5 where only 19 animals were included. Standard error of the mean (SEM) was calculated with 20 replications. For processing method 59 and 60 animals were included in steam and dry rolled means, respectively.

[2]Means for barley lots and SEM were based upon four pens per treatment. For processing method there were 12 observations per mean.

Table 3.8. Least squares means of carcass traits, liver abscesses and grading percentages for steers by barley lot and processing method.

Item	Barley lot number								Processing method			
	1	2	3	4	5	6	SEM[1]	Probability	SR	DR	SEM[1]	Probability
Final wt (kg)	507.0	512.0	507.6	507.6	511.1	509.3	6.6	0.99	508.0	510.2	3.7	0.67
Carcass wt (kg)	289.9	291.7	291.2	289.3	293.6	289.9	4.7	0.99	288.4	293.5	2.6	0.17
Dressing percentage (%)	57.1	57.0	57.4	57.0	57.4	56.9	0.4	0.91	56.8	57.5	0.2	0.03
Fat depth (cm)	1.46	1.22	1.40	1.22	1.41	1.40	0.04	0.08	1.32	1.38	0.04	0.31
Grade fat (cm)	1.28	1.10	1.26	1.12	1.29	1.21	0.08	0.40	1.18	1.24	0.05	0.44
Rib eye (cm^2)	72.9	78.8	75.9	74.5	74.2	74.0	2.0	0.33	75.2	74.8	1.1	0.77
Marbling[2]	7.4	7.2	7.6	7.4	7.4	7.3	0.1	0.37	7.4	7.3	0.1	0.35
Cutability (%)	56.6[b]	58.2[a]	57.4[ab]	57.7[ab]	57.2[ab]	57.2[ab]	0.3	0.02	57.5	57.3	0.2	0.55
Liver abcesses (%)	35.0	42.1	40.0	47.4	30.0	47.4		0.84	36.8	43.3		0.52
Grade (%) B1	0.0	0.0	5.0	0.0	0.0	0.0		1.00	1.7	0.0		0.81
A1	55.6	30.0	5.0	35.0	35.0	33.3			37.9	25.9		
A2	22.2	50.0	80.0	60.0	50.0	44.4			44.8	58.6		
A3	22.2	20.0	5.0	5.0	15.0	22.2			15.5	13.8		
A4	0.0	0.0	5.0	0.0	0.0	0.0			0.0	1.7		

[1]Standard error of the mean based on 18 observations per barley lot and 58 observations per processing method.
[2]1=most marbled; 9=least marbled.

Table 3.9. Least squares means of glucose released from alpha-linked polymers in barley grain by an amylase (mg g^{-1} dry matter)

Item	1h	2h	27h
Barley lot no.			
1	138[a]	222[a]	503[a]
2	139[a]	228[a]	469[a]
3	118[ab]	181[b]	420[b]
4	111[b]	185[b]	413[b]
5	120[ab]	183[b]	497[a]
6	129[ab]	201[ab]	439[b]
SEM[1]	6.3	9.2	15.5
Probability	<0.01	<0.01	<0.01
Processing method			
None	121[b]	201[c]	469
Dry rolled	117[b]	179[b]	445
Steam rolled	140[a]	221[a]	455
SEM[1]	4.5	6.5	11.1
Probability	<0.01	<0.01	0.26
Interaction			
Probability	0.06	<0.01	0.03

[a-c]Means within columns with different superscripts are significantly different($P < 0.05$).

[1]Standard error of the mean is based on eight samples per barley lot and 16 samples per processing method.

Table 3.10. Least squares means of barley dry matter (DM), starch, and beta-glucan (BG) disappearance (%) from nylon bags incubated in the rumen for 0, 8 or 24 h.

Item	0 h			8 h			24 h
	DM	BG	Starch	DM	BG	Starch	DM
Barley lot no.							
1	49.2[e]	61.4	59.3	76.5[c]	94.5[ab]	93.8[b]	80.7[c]
2	51.1[d]	69.3	63.4	75.4[c,d]	93.8[b]	90.7[e]	81.0[c]
3	55.2[b]	69.5	68.7	78.2[b]	95.4[ab]	92.8[c]	82.8[b]
4	46.8[f]	70.4	62.4	74.6[d]	93.8[b]	92.9[c]	78.6[d]
5	53.3[c]	69.7	67.1	78.4[b]	96.2[a]	91.7[d]	83.9[ab]
6	59.1[a]	68.0	76.0[a]	82.2[a]	95.5[ab]	97.1[a]	84.6[a]
SEM[1]	0.44	1.99	2.29	0.43	0.44	0.26	0.55
Probability	<0.01	0.07	<0.01	<0.01	0.01	<0.01	<0.01
Processing method							
Steam rolled	47.5	63.8	58.3	71.6	93.9	86.8	78.8
Dry rolled	57.4	72.3	74.0	83.5	95.9	99.5	85.2
SEM[2]	0.25	1.15	1.32	0.25	0.25	0.15	0.32
Probability	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Interaction							
Probability	<0.01	0.17	0.15	<0.01	0.32	<0.01	0.24

[a-f]Means within columns with different superscripts are significantly different ($P<0.05$).

[1]Standard error of the mean based on 16 samples per barley lot for DM and four for BG and starch.

[2]Standard error of the mean based on 48 samples per barley lot for DM and 12 for BG and starch.

Table 3.11. Estimates of regression coefficients, standard errors (SE) and equation probabilities (P) between selected chemical components of barley, in vitro and in situ results, and feedlot performance

Independant variable	Statistic estimated	Dependant variables: Dry matter intake (kg d^{-1}) Estimates	SE	P	R^2	Dry matter:gain ratio Estimates	SE	P	R^2
BG[1]	a	10.74	1.17	<0.01		7.59	0.58	<0.01	
	b	-0.32	0.28	0.31	0.25	-0.36	0.14	0.06	0.62
Starch	a	13.78	1.91	<0.01		9.53	1.15	<0.01	
	b	-0.07	0.03	0.08	0.57	-0.05	0.02	0.04	0.69
NDF[2]	a	7.59	0.57	<0.01		4.81	0.39	<0.01	
	b	0.10	0.03	0.03	0.72	0.07	0.02	0.03	0.73
ADF[3]	a	8.24	0.51	<0.01		5.07	0.17	<0.01	
	b	0.16	0.07	0.08	0.57	0.13	0.02	<0.01	0.90
VW[4]	a	12.37	0.92	<0.01		8.11	0.72	<0.01	
	b	-0.05	0.01	0.03	0.73	-0.03	0.01	0.05	0.66
In situ DMD8[5]	a	16.11	2.72	<0.01		10.57	2.09	<0.01	
	b	-0.09	0.04	0.07	0.60	-0.05	0.03	0.10	0.53
In situ DMD24[6]	a	18.70	2.79	<0.01		13.08	1.61	<0.01	
	b	-0.11	0.03	0.03	0.74	-0.09	0.02	0.01	0.83
In situ BGD8[7]	a	37.19	4.49	<0.01		23.33	5.72	0.02	
	b	-0.29	0.05	<0.01	0.91	-0.18	0.06	0.04	0.69

[1] Beta-glucan (% dry matter).
[2] Neutral detergent fiber (% dry matter).
[3] Acid detergent fiber (% dry matter).
[4] Volume weight (kg h L^{-1}, air dry).
[5] % dry matter disappearance after 8 h in situ.
[6] % dry matter disappearance after 24 h in situ.
[7] % beta-glucan disappearance after 8 h in situ.

Table 3.12. Least squares means for chemical composition and percent apparent digestibility of various chemical components of barley of different volume weights

Volume Weight	Dry matter	Protein	Starch	Beta-glucan	NDF[2]	ADF[3]
Composition (%)						
Light (43.0 kg hL^{-1})	88.4	11.3	60.2	2.7	23.9	10.3
Medium (58.9 kg hL^{-1})	87.0	12.6	62.3	4.0	16.3	7.3
Heavy (63.7 kg hL^{-1})	87.5	12.4	62.3	4.7	17.9	8.1
Extra heavy (66.2 kg hL^{-1})	88.7	13.1	63.5	4.4	17.5	7.3
Apparent digestibility (%)						
Light	76.8	66.5	98.5	99.0	33.3	25.8
Medium	80.3	73.9	98.3	98.1	29.0	28.9
Heavy	81.0	74.8	97.3	98.1	32.3	30.9
Exheavy	80.1	71.0	98.2	99.0	28.6	31.0
SEM[4]	1.20	2.12	0.45	0.39	4.36	4.15
Probability	0.12	0.07	0.27	0.25	0.70	0.79

[1] Beta-glucan.
[2] Neutral detergent fiber.
[3] Acid detergent fiber.
[4] Standard error of the mean based on five observations per treatment.

4. GENERAL DISCUSSION AND CONCLUSIONS

Barley Quality

Although the barleys used in these experiments differed ($P < 0.05$) in beta-glucan, starch, protein, ADF and NDF content, no differences in animal performance were apparent. This is consistant with other work conducted in Alberta (Mathison and Milligan 1984; Grimson et al. 1987). However, in the present experiments significant ($P < 0.05$) regressions existed between DM:G ratios and several components of the barleys. Acid detergent fiber content was the most useful independent variable ($R^2 = 0.90$) which is somewhat surprising since it comprised less than 10% of the DM of any of the barleys. As independant variables NDF, starch, VW and beta-glucan were somewhat useful as indicated by R^2 values of 0.73, 0.69 0.66, and 0.62, respectively. Volume weight is the easiest of all these components to measure and is frequently used as the basis for trade (Agriculture Canada 1987; Grimson et al. 1987). Based on results presented in this thesis, whenever laboratory analyses are being conducted on a sample of barley the determination of ADF is recommended. It is much easier to determine than NDF (Dr. H. Hsu, personal communication) and based on the results presented is a better indicator of barley quality for cattle.

As an independant variable, in situ DM disappearance after 24 h produced a useful regression ($R^2 = 0.83$) with DM:G ratio. Thus, in situ disappearance of DM can be considered a useful measurment in the

screening of new barley cultivars to be fed to cattle. Additional in situ work to characterize the degradation of barley through the first 8 h of digestion should be considered.

From the results presented beta-glucans do not appear to have an adverse affect on the digestion and utilization of barley by cattle. Beta-glucans are rapidly digested in the rumen as indicated by 8 h in situ disappearance values of 93.8 to 96.2%. Comparable values for starch were 90.9 to 97.1%. Total tract apparent digestibility is also similiar to starch and thus beta-glucans can be considered to be part of the rapidly digested carbohydrate fraction. Additional experimental work to determine the effect of beta-glucan content of barley on the viscosity, foaminess and surface tension of rumen fluid is not yet complete.

Processing Method

The results presented indicate that steam rolling of barley for finishing cattle is not warranted. No improvement over dry rolled barley in feed intake, ADG or DM:G ratio was observed. This is in agreement with other work in Alberta (Mathison and Milligan 1984; Grimson et al. 1987). The greater in situ disappearance of starch, DM and beta-glucan from dry rolled barley may be partially responsible for this observation. Additional work on the effect of steam rolling, tempering and other treatments on initial rates of digestion in situ should be considered.

4.1 REFERENCES

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Appendix 1-Methods of starch and beta-glucan analysis

Air dry samples were ground through a 1 mm screen in a laboratory mill (Christy and Norris Ltd., Chelmsford, England) and stored in plastic capped vials prior to analysis.

Starch hydrolysis

In this procedure, adapted from McRae and Armstrong (1968), 0.2 g of ground barley (1 mm screen) was mixed with 50 mL of de-ionized water, 2 mL of NaF (4% wt/vol) and 50 ml of acetate buffer (0.2 M sodium acetate plus glacial acetic acid, pH =4.5). Amyloglucosidase enzyme (Aspergillus niger, No. A3514, Sigma Chem. Co., St. Louis, MO.) (0.5 mL) was added and the material was incubated at 60°C. At intervals of 1, 2, and 27 h after the start of incubation, 1 mL aliquots were taken and clarified with 1 mL addition of 0.3 N barium hydroxide and 0.3 N zinc sulphate. Soluble potato starch (Sigma Chem. Co. No. 5-2630) was used to standardize the procedure. After centrifuging at 1000 g for 8-10 min a 30 µL aliquot was then removed for the determination of free glucose. Glucose was determined using the hexokinase- glucose-6- phosphate dehydrogenase kit of Sigma Diagnostics (No. 115-A). This method has been used by others, (Bamforth 1983), and relies on the colorimetric measurement (520 nm) of reduced iodonitrotetrazolium. Appropriate standards, substrate and enzyme blanks were included.

Beta-glucan analysis

Eighty to 100 mg of ground sample was weighed into a 10 mL centrifuge tube. Five mL of 80% (vol/vol) ethanol was added and the mixture was boiled gently for 5 min in a water bath (90°C). This step inactivated endogenous enzymes and removed soluble sugars. Centrifuging at 1000 g for 10 min followed by discarding of the supernatant removed most of the ethanol from the sample. Leaving the tubes in an oven (40°C, 16 h) with the tops off provided complete removal of ethanol. Five mL of buffer solution (50 mM sodium acetate plus glacial acetic acid, pH = 5.0) was mixed with the sample and centrifuging as above was done. This step was repeated once before 2.5 mL of buffer and 300 µL of the purified beta-glucanase were added to the sample. Incubation (40°C, 16 h) with shaking followed. Increasing the amount of beta-glucanase to 1 mL per sample allowed incubation time to be reduced to 4 h and this was done on a portion of the samples. After incubation the samples were again centrifuged as above. Glucose was determined in the supernatant as described previously.

Starch analysis

Starch was determined on the same samples using a modification of the method of Salmonsson et al. (1984). Samples were prepared as indicated for beta-glucan determination. Fifty to 60 mg of ground sample was weighed into a 50 mL test tube along with 25 mL of buffer (0.2 M sodium acetate plus glacial acetic acid, pH = 4.6) and 100 µL

of a thermostable bacterial alpha-amylase (Temamyl, 60L, Nova Industries A/S, Bagsvaerd, Denmark). The tube was placed in a water bath (90°C) for 45 min with occasional shaking. After cooling 80 μL of amyloglucosidase (Aspergillus niger, Sigma Chem. Co. NO. A3514) was added and the contents were incubated for 18 h (60°C) with continuous shaking. Approximatley 2 mL were then removed from the tube and centrifuged at 2000 g for 5 min. The clear supernatant was analyzed for glucose as described previously.